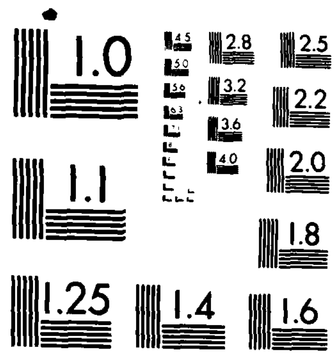
AD-A161 880 SURVEY AND EVALUATION OF FIELD DATA SUITABLE FOR SMOKE HAZARD MODEL EVALUATION(U) ARGONNE NATIONAL LAB IL A J POLICASTRO ET AL SEP 85 ANL/ER-85-3 1/1

UNCLASSIFIED F/G 4/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

1

AD ____________________

SURVEY AND EVALUATION OF FIELD DATA SUITABLE FOR SMOKE HAZARD MODEL EVALUATION

Anthony J. Policastro
Argonne National Laboratory
Argonne, Illinois 60439

and

William E. Dunn
University of Illinois
Urbana, Illinois 61801

SEPTEMBER 1985

Supported by
U.S. ARMY MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Fort Detrick, Frederick, MD 21701

Contract No. 84PP4822

Project Officer: Major David Parmer
Health Effects Research Division
U.S. ARMY MEDICAL BIOENGINEERING RESEARCH AND DEVELOPMENT LABORATORY
Fort Detrick, Frederick, MD 21701

Approved for public release;
distribution unlimited

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

AD-A161 880

REPORT DOCUMENTATION PAGE

- **1a. REPORT SECURITY CLASSIFICATION:** Unclassified
- **1b. RESTRICTIVE MARKINGS:** None
- **2a. SECURITY CLASSIFICATION AUTHORITY:** Argonne National Laboratory
- **2b. DECLASSIFICATION / DOWNGRADING SCHEDULE:**
- **3. DISTRIBUTION / AVAILABILITY OF REPORT:** Approved for public release; distribution unlimited
- **4. PERFORMING ORGANIZATION REPORT NUMBER(S):** ANL/ER-85-3
- **5. MONITORING ORGANIZATION REPORT NUMBER(S):** N/A
- **6a. NAME OF PERFORMING ORGANIZATION:** Argonne National Laboratory & University of Illinois
- **6b. OFFICE SYMBOL (If applicable):** ERD
- **7a. NAME OF MONITORING ORGANIZATION:** Health Effects Research Division, U.S. Army Medical Bioengineering Res. & Development Lab
- **6c. ADDRESS (City, State, and ZIP Code):** Argonne National Laboratory; 9700 S. Cass, Argonne, IL 60439 and University of Illinois, 1206 W. Green Street, Urbana, IL 61801
- **7b. ADDRESS (City, State, and ZIP Code):** Fort Detrick, Frederick, MD 21701
- **8a. NAME OF FUNDING / SPONSORING ORGANIZATION:** See 7a.
- **8b. OFFICE SYMBOL (If applicable):** USAMBRDL
- **9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:**
- **8c. ADDRESS (City, State, and ZIP Code):** Fort Detrick, Frederick, MD 21701
- **10. SOURCE OF FUNDING NUMBERS:**

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

- **11. TITLE (Include Security Classification):** Survey and Evaluation of Field Data Suitable for Smoke Hazard Model Evaluation (Unclassified)
- **12. PERSONAL AUTHOR(S):** Anthony J. Policastro and William E. Dunn
- **13a. TYPE OF REPORT:** Technical Report
- **13b. TIME COVERED:** FROM 1984 TO 1985
- **14. DATE OF REPORT (Year, Month, Day):** 1985, September
- **15. PAGE COUNT:** 61
- **16. SUPPLEMENTARY NOTATION:**

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

aerosol photometer, dosages, military smokes, atmospheric dispersion, fog oil, plume models, chemical impinger, particle size distribution

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

This report presents a summary and critical evaluation of the existing data on the dispersion of military smokes. Emphasis is placed on fog oil smokes in terms of the measurement of concentration, dosage, particle size distribution, and mass deposition rate. The suitability of the available data for evaluating dispersion models for health and environmental impacts pruposes is marginal. Several questions remain as to the adequacy of the sampling techniques used and the validity of some of the supporting meteorological data. The best of the existing data on fog oil smoke dispersion were acquired during the Smoke Week III and IV experiments.

- **20. DISTRIBUTION / AVAILABILITY OF ABSTRACT:** ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS
- **21. ABSTRACT SECURITY CLASSIFICATION:** Unclassified
- **22a. NAME OF RESPONSIBLE INDIVIDUAL:** Dr. Anthony J. Policastro
- **22b. TELEPHONE (Include Area Code):** 312/972-3235
- **22c. OFFICE SYMBOL:** ERD

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

18. Smoke Week Data

Block 9. Procurement Instrument Identification Number: For a contractor grantee report, enter the complete contract or grant number(s) under which the work was accomplished. Leave this block blank for in-house reports.

Block 10. Source of Funding (Program Element, Project, Task Area, and Work Unit Number(s): These four data elements relate to the DoD budget structure and provide program and/or administrative identification of the source of support for the work being carried on. Enter the program element, project, task area, work unit accession number, or their equivalents which identify the principal source of funding for the work required. These codes may be obtained from the applicable DoD forms such as the DD Form 1498 (Research and Technology Work Unit Summary) or from the fund citation of the funding instrument. If this information is not available to the authoring activity, these blocks should be filled in by the responsible DoD Official designated in Block 22. If the report is funded from multiple sources, identify only the Program Element and the Project, Task Area, and Work Unit Numbers of the principal contributor.

Block 11. Title: Enter the title in Block 11 in initial capital letters exactly as it appears on the report. Titles on all classified reports, whether classified or unclassified, must be immediately followed by the security classification of the title enclosed in parentheses. A report with a classified title should be provided with an unclassified version if it is possible to do so without changing the meaning or obscuring the contents of the report. Use specific, meaningful words that describe the content of the report so that when the title is machine-indexed, the words will contribute useful retrieval terms.

If the report is in a foreign language and the title is given in both English and a foreign language, list the foreign language title first, followed by the English title enclosed in parentheses. If part of the text is in English, list the English title first followed by the foreign language title enclosed in parentheses. If the title is given in more than one foreign language, use a title that reflects the language of the text. If both the text and titles are in a foreign language, the title should be translated, if possible, unless the title is also the name of a foreign periodical. Transliterations of often used foreign alphabets (see Appendix A of MIL-STD-847B) are available from DTIC in document AD-A080 800.

Block 12. Personal Author(s): Give the complete name(s) of the author(s) in this order: last name, first name, and middle name. In addition, list the affiliation of the authors if it differs from that of the performing organization.

List all authors. If the document is a compilation of papers, it may be more useful to list the authors with the titles of their papers as a contents note in the abstract in Block 19. If appropriate, the names of editors and compilers may be entered in this block.

Block 13a. Type of Report: Indicate whether the report is summary, final, annual, progress, interim, etc.

Block 13b. Time Covered: Enter the inclusive dates (*year, month, day*) of the period covered, such as the life of a contract in a final contractor report.

Block 14. Date of Report: Enter the year, month, and day, or the year and the month the report was issued as shown on the cover.

Block 15. Page Count: Enter the total number of pages in the report that contain information, including cover, preface, table of contents, distribution lists, partial pages, etc. A chart in the body of the report is counted even if it is unnumbered.

Block 16. Supplementary Notation: Enter useful information about the report in hand, such as: "Prepared in cooperation with...," "Translation at (or by)...," "Symposium...," If there are report numbers for the report which are not noted elsewhere on the form (such as internal series numbers or participating organization report numbers) enter in this block.

Block 17. COSATI Codes: This block provides the subject coverage of the report for announcement and distribution purposes. The categories are to be taken from the "COSATI Subject Category List" (DoD Modified), Oct 65, AD-624 000. A copy is available on request to any organization generating reports for DoD. At least one entry is required as follows:

Field - to indicate subject coverage of report.

Group - to indicate greater subject specificity of information in the report.

Sub-Group - if specificity greater than that shown by Group is required, use further designation as the numbers after the period (.) in the Group breakdown. Use only the designation provided by AD-624 000.

Example: The subject "Solid Rocket Motors" is Field 21, Group 08, Subgroup 2 (page 32, AD-624 000).

Block 18. Subject Terms: These may be descriptors, keywords, posting terms, identifiers, open-ended terms, subject headings, acronyms, code words, or any words or phrases that identify the principal subjects covered in the report, and that conform to standard terminology and are exact enough to be used as subject index entries. Certain acronyms or "buzz words" may be used if they are recognized by specialists in the field and have a potential for becoming accepted terms. "Laser" and "Reverse Osmosis" were once such terms.

If possible, this set of terms should be selected so that the terms individually and as a group will remain UNCLASSIFIED without losing meaning. However, priority must be given to specifying proper subject terms rather than making the set of terms appear "UNCLASSIFIED." Each term on classified reports must be immediately followed by its security classification, enclosed in parentheses.

For reference on standard terminology the "DTIC Retrieval and Indexing Terminology" DRIT-1979, AD-A068 500, and the DoD "Thesaurus of Engineering and Scientific Terms (TEST) 1968, AD-672 000, may be useful.

Block 19. Abstract: The abstract should be a pithy, brief (preferably not to exceed 300 words), factual summary of the most significant information contained in the report. However, since the abstract may be machine-searched, all specific and meaningful words and phrases which express the subject content of the report should be included, even if the word limit is exceeded.

If possible, the abstract of a classified report should be unclassified and consist of publicly releasable information (Unlimited), but in no instance should the report content description be sacrificed for the security classification.

NOTE: **An unclassified abstract describing a classified document may appear separately from the document in an unclassified context e.g., in DTIC announcement or bibliographic products. This must be considered in the preparation and marking of unclassified abstracts.**

For further information on preparing abstracts, employing scientific symbols, verbalizing, etc., see paragraphs 2.1(n) and 2.3(b) in MIL-STD-847B.

Block 20. Distribution / Availability of Abstract: This block must be completed for all reports. Check the applicable statement: "unclassified / unlimited," "same as report," or, if the report is available to DTIC registered users " DTIC users."

Block 21. Abstract Security Classification: To ensure proper safeguarding of information, this block must be completed for all reports to designate the classification level of the entire abstract. For CLASSIFIED abstracts, each paragraph must be preceded by its security classification code in parentheses.

Block 22a,b,c. Name, Telephone and Office Symbol of Responsible Individual: Give name, telephone number, and office symbol of DoD person responsible for the accuracy of the completion of this form.

INSTRUCTIONS FOR PREPARATION OF REPORT DOCUMENTATION PAGE

GENERAL INFORMATION

The accuracy and completeness of all information provided in the DD Form 1473, especially classification and distribution limitation markings, are the responsibility of the authoring or monitoring DoD activity.

Because the data input on this form will be what others will retrieve from DTIC's bibliographic data base or may determine how the document can be accessed by future users, care should be taken to have the form completed by knowledgeable personnel. For better communication and to facilitate more complete and accurate input from the originators of the form to those processing the data, space has been provided in Block 22 for the name, telephone number, and office symbol of the DoD person responsible for the input cited on the form.

All information on the DD Form 1473 should be typed.

Only information appearing on or in the report, or applying specifically to the *report* in hand, should be reported. If there is any doubt, the block should be left blank.

Some of the information on the forms (e.g., title, abstract) will be machine indexed. The terminology used should describe the content of the report or identify it as precisely as possible for future identification and retrieval.

NOTE: Unclassified abstracts and titles describing classified documents may appear separately from the documents in an unclassified context, e.g., in DTIC announcement bulletins and bibliographies. This must be considered in the preparation and marking of unclassified abstracts and titles.

The Defense Technical Information Center (DTIC) is ready to offer assistance to anyone who needs and requests it. Call Data Base Input Division, Autovon 284-7044 or Commercial (202) 274-7044.

SECURITY CLASSIFICATION OF THE FORM

In accordance with DoD 5200.1-R, Information Security Program Regulation, Chapter IV Section 2, paragraph 4-200, classification markings are to be stamped, printed, or written at the top and bottom of the form in capital letters that are larger than those used in the text of the document. See also DoD 5220.22-M, Industrial Security Manual for Safeguarding Classified Information, Section II, paragraph 11a(2). This form should be unclassified, if possible.

SPECIFIC BLOCKS

Block 1a. Report Security Classification: Designate the highest security classification of the report. (See DoD 5220.1-R, Chapters I, IV, VII, XI, Appendix A.)

Block 1b. Restricted Marking: Enter the restricted marking or warning notice of the report (e.g., CNWDI, RD, NATO).

Block 2a. Security Classification Authority: Enter the commonly used markings in accordance with DoD 5200.1-R, Chapter IV, Section 4, paragraph 4-400 and 4-402. Indicate classification authority.

Block 2b. Declassification / Downgrading Schedule: Indicate specific date or event for declassification or the notation, "Originating Agency Determination Required" or "OADR." Also insert (when applicable) downgrade to ____________ on ____________ (e.g., Downgrade to Confidential on 6 July 1983). (See also DoD 5220.22-M, Industrial Security Manual for Safeguarding Classified Information, Appendix II.)

NOTE: **Entry must be made in Blocks 2a and 2b except when the original report is unclassified and has never been upgraded.**

Block 3. Distribution/Availability Statement of Report: Insert the statement as it appears on the report. If a limited distribution statement is used, the reason must be one of those given by DoD Directive 5200.20, Distribution Statements on Technical Documents, as supplemented by the 18 OCT 1983 SECDEF Memo, "Control of Unclassified Technology with Military Application." The Distribution Statement should provide for the broadest distribution possible within limits of security and controlling office limitations.

Block 4. Performing Organization Report Number(s): Enter the unique alphanumeric report number(s) assigned by the organization originating or generating the report from its research and whose name appears in Block 6. These numbers should be in accordance with ANSI STD 239.23-74, "American National Standard Technical Report Number." If the Performing Organization is also the Monitoring Agency, enter the report number in Block 4.

Block 5. Monitoring Organization Report Number(s): Enter the unique alphanumeric report number(s) assigned by the Monitoring Agency. This should be a number assigned by a DoD or other government agency and should be in accordance with ANSI STD 239.23-74. If the Monitoring Agency is the same as the Performing Organization, enter the report number in Block 4 and leave Block 5 blank.

Block 6a. Name of Performing Organization: For in-house reports, enter the name of the performing activity. For reports prepared under contract or grant, enter the contractor or the grantee who generated the report and identify the appropriate corporate division, school, laboratory, etc., of the author.

Block 6b. Office Symbol: Enter the office symbol of the Performing Oganization.

Block 6c. Address: Enter the address of the Performing Organization. List city, state, and ZIP code.

Block 7a. Name of Monitoring Organization: This is the agency responsible for administering or monitoring a project, contract, or grant. If the monitor is also the Performing Organization, leave Block 7a. blank. In the case of joint sponsorship, the Monitoring Organization is determined by advance agreement. It can be either an office, a group, or a committee representing more than one activity, service, or agency.

Block 7b. Address: Enter the address of the Monitoring Organization. Include city, state, and ZIP code.

Block 8a. Name of Funding/Sponsoring Organization: Enter the full official name of the organization under whose immediate funding the document was generated, whether the work was done in-house or by contract. If the Monitoring Organization is the same as the Funding Organization, leave 8a blank.

Block 8b. Office Symbol: Enter the office symbol of the Funding/Sponsoring Organization.

Block 8c. Address: Enter the address of the Funding/Sponsoring Organization. Include city, state and ZIP code.

AD ______________________

SURVEY AND EVALUATION OF FIELD DATA SUITABLE FOR SMOKE HAZARD MODEL EVALUATION

Anthony J. Policastro
Argonne National Laboratory
Argonne, Illinois 60439

and

William E. Dunn
University of Illinois
Urbana, Illinois 61801

SEPTEMBER 1985

Supported by
U.S. ARMY MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Fort Detrick, Frederick, MD 21701

Contract No. 84PP4822

Project Officer: Major David Parmer
Health Effects Research Division
U.S. ARMY MEDICAL BIOENGINEERING RESEARCH AND DEVELOPMENT LABORATORY
Fort Detrick, Frederick, MD 21701

NOTICE

Disclaimer

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Disposition

Destroy this report when it is no longer needed. Do not return it to the originator.

EXECUTIVE SUMMARY

This report presents a summary and critical evaluation of the existing data on the dispersion of military smokes. Emphasis is placed on the measurement of concentration, dosage (time-integrated concentration), particle size distribution and mass deposition rate. The data are evaluated both in terms of their overall reliability and, equally important, in terms of their suitability for testing models available for use in assessing the hazards of smokes.

The best available data were obtained during the Smoke Week III and Smoke Week IV experiments. The primary purpose of these experiments was to study the relationship between smoke concentration and obscuration as measured by transmission loss along a line of sight passing through the plume. In a typical run, 40 to 50 concentration samplers were set out along two transects approximately normal to the expected plume centerline. Transmission along each line of sight was measured using a transmitter/receiver pair spanning the transect. Each sampling station along the transect typically consisted of an aerosol photometer to measure instantaneous concentration and a chemical impinger to measure time-integrated concentration, the latter data being used to scale the relative concentrations recorded by the aerosol photometers. In some cases, the particle size distribution was measured at a single instrument station located about 50 m from the source.

Owing to the emphasis placed on understanding the obscuration effectiveness of the smoke, correspondingly less attention was paid to defining the relationship between source characteristics and downwind concentrations. Moreover, no deposition rate measurements were made and only distances out to about 100 m from the source were covered. Such testing characteristics fall far short of the distances and generator run times of interest in assessing environmental and civilian health impacts.

The suitability of the available data for evaluating dispersion models is marginal and several questions remain as to the adequacy of the sampling techniques used and the validity of some of the supporting meteorological data. For example, a serious question surrounds the dosage measurements wherein subjective adjustments of unknown validity were applied to make sense of the chemical impinger data. Despite the limitations inherent in the data, a systematic evaluation of data consistency and comparison with model predictions can add to the overall knowledge base of the present project.

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of Mr. Howard Smalley of the Office of Project Manager Smoke/Obscurants for providing us with the key references on the Smoke Week data. The authors also wish to thank Dr. Michael Farmer of Science and Technology Corporation and Mr. Lew Nielsen of Dugway Proving Ground for their valuable discussions on the quality of the Smoke Week data. Finally, the authors would like to thank Major David Parmer and Mr. Jesse Barkley of the U.S. Army Medical Bioengineering Research and Development Laboratory for their support and direction of the present project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

This report provides a first step in our evaluation of smoke/obscurant models for the US Army Medical Research and Development Command (USAMRDC). The overall project goal is to characterize the field concentrations of smokes to the point that it will be possible to evaluate their environmental impacts in field training exercises. Of concern in these exercises are impacts to civilians and indigenous plants and wildlife. To meet this need, two objectives have been set forth: (1) carry out a comprehensive field measurement program to obtain high quality data on the dosages and deposition rates and particle size distributions produced by specific military smoke generating devices, and (2) use these field data, combined with results that can be synthesized from other studies of smokes, to evaluate the performance of predictive models.

Since this work will ultimately be synthesized with results of toxicological studies on health effects and with impact studies on flora, fauna, and wildlife, one criterion by which to evaluate the existing field data is in terms of the data requirements of these biological studies.

Ongoing toxicological studies[1] on the health effects of military smokes have been focusing on the acute and subchronic response of animals to smoke concentrations. Toxicologists are primarily interested in a characterization of field exposures in terms of, say, the decay of concentration with distance for a wide variety of meteorological and generator operating conditions. Secondly, toxicologists are interested in evaluating the representativeness of their chosen laboratory exposures (generally constant concentrations) to actual field conditions. It is recognized that the exposures to troops in the field are not represented by constant concentrations with time, and involve concentration fluctuations that are thought to vary by as much as a factor of ten (between peak and valley) about the mean. Although the major effect on animals and humans may be most represented by total exposure in terms of a dosage-type quantity, interest exists among toxicologists in documenting fluctuations about the average value of concentration. Unfortunately, no data currently exist on the acute or subchronic response of such smoke concentration fluctuations by animals or humans.

Also important from an inhalation toxicology standpoint is the particle size distribution of the smoke. The respirable fraction (sizes less than 10 microns) can enter deep into the lungs and remain there possibly causing physical damage. The precise health effects (if any) will depend upon the physical and chemical characteristics of the smoke that is respirated.

In addition to human (mammalian) health effects of smokes, interest also lies in the impacts to flora and fauna, and to wildlife. In order to analyze such impacts, knowledge of the deposition rates of the various smokes should be studied as well. Current project objectives focus on the measurement of dosages, deposition rates, and particle size distributions. The measurement of concentration fluctuations with time may be considered at a later date.

This report also initiates the model validation work for the project by providing a review of existing field data on the dispersion of smokes and

obscurants used by the U.S. Army. The current phase of the project is aimed at determining field concentrations and the performance of models for fog oil smoke dispersion. Although general interest extends to all smoke types, this report shall thereby focus on fog oil in choosing examples which illustrate the scope and quality of data available. As the current project extends to other smoke types other than fog oil, supplements to this report covering the existing data on those particular smoke types will be prepared.

Most of the existing data on smokes found in the literature were acquired during the annual Smoke Week experiments held by the Office of Project Manager Smoke/Obscurants and are available in published Smoke Week reports and supporting Dugway Proving Gound (DPG) and Atmospheric Sciences Lab (ASL) reports. The purpose of this document then is to present:

(a) a summary review of the typical concentration and particle size measurement programs carried out in these Smoke Week experiments,

(b) samples of the data that are available from the typical measurement programs

(c) an evaluation of the quality of these data for the purpose of smoke transport model testing, and

(d) the plan to employ these data in the model validation program.

An important point which warrants emphasis is the difference between the objectives of the Smoke Week experiments and those of the present project from which perspective the data will be evaluated.. In the former case, interest was focused on better understanding the relationship between transmission reduction along a line of sight through the plume and the instantaneous local concentrations along that same line of sight. As such, less attention was devoted to the study of the relationship between source characteristics and measured downwind concentrations, a primary concern of the present project. Also, the Smoke Week measurements were made close to the source (to about 100 m) where the greatest interest in obscuration effectiveness lies. In contrast, distances up to 2000 m and greater are important in the study of potential environmental and civilian health effects. Smoke Week measurements involved generator run times typically of about 10 minutes. To determine troop exposure levels, generator runs of much longer duration (approximately one hour or longer) are necessary to correctly represent current and future field applications of smoke releases from fog-oil generators. Lastly, the Smoke Week experiments do not include measurements of deposition rate, a parameter of importance to the present effort. Given these vast differences between the needs of the present project and the objectives of past experiments, the available data cannot provide a thorough test of existing models. Yet, a systematic evaluation of these data for internal consistency and against the predictions of existing models is nevertheless a worthwhile endeavor, since the results should highlight several measurement and modeling issues and thus add to the knowledge base of the present project.

DESCRIPTION OF IDEAL DATA SET

To provide the backdrop against which existing data are to be evaluated, it is useful to define an ideal data set which includes all measurements necessary for complete evaluation of the broad spectrum of available models. Yet, it is unfair to evaluate any experimental data against a theoretical ideal since such an ideal is never practically attainable due to cost and logistics limitations. For example, as complex measurements of microscale phenomena are added, quality assurance problems on data reliability escalate rapidly. Thus, a far more practical question concerns the minimum set of measured parameters necessary to define model performance and to isolate the causes of poor performance. The parameters chosen should be those which can, in fact, be measured accurately and with high reliability under actual field conditions. Moreover, the measured quantities should be statistically significant in terms of defining model performance.

The measurements fall into three broad categories: source definition, meteorology definition and plume definition. Each of these is considered individually below.

SOURCE DEFINITION

Necessary source characteristics include:

(a) the location(s) and elevation(s) and exit diameter(s) of the smoke release point(s) and the direction of smoke plume release when a smoke generator or vehicle exhaust is utilized,

(b) the mass release rate (kg/s) of smoke material as a function of time over the entire period of smoke generation,

(c) the particle size distribution and composition of material as it leaves the generating device, and

(d) the exit temperature and velocity of the smoke plume also as a function of time.

The necessity for measuring the time-dependent release rate of smoke material is clear. In many cases, the total mass consumed over the entire period of operation is all that is available. In addition, the exit temperature and velocity of the plume are important for determining plume buoyancy. The direct measurement of particle size distribution and composition at the exit is also necessary for our purposes.

METEOROLOGY DEFINITION

Measurements of the ambient meteorology during a smoke release ought to relate closely to the atmospheric inputs required by the models to be

evaluated. Input requirements of models involving different theoretical approaches (e.g. Gaussian and Monte Carlo) should be included in the listing of the meteorological inputs to be measured. Consideration should be given not only to existing models but also to new models that may be developed as improvements to existing classes of models.

Based on a survey of the meteorological requirements of the popular and promising models (see later discussion), the following data are required:

(a) wind speed, wind direction, sigma-theta, and sigma-phi at the average height of the plume (taken typically as 10-m for most fog-oil plumes),

(b) the variation of wind speed and direction with elevation above the ground including a wind speed profile power-law exponent,

(c) roughness height and friction velocity,

(d) mixing height (important in model predictions under inversion type meteorological conditions),

(e) vertical variation of temperature with height, and

(f) Pasquill stability class (otherwise, the raw data required to determine the class; i.e., wind speed, cloud height, cloud cover, and solar radiation).

A number of models require the meteorological inputs as a function of time whereas others require these variables as a time average over the period of release. Most models require meteorological inputs at one spatial location near the smoke release point. Some advanced models permit the simultaneous input of wind speeds and directions at different spatial locations for each of a sequence of meteorological time periods. Algorithms are then provided for the estimation of the winds at all other spatial locations and time.

Considering the requirement in some models for turbulence measurements (sigma-theta and sigma-phi), and the need in some models for a vertical profile of wind speed, wind direction, and temperature, it is most appropriate to obtain such measurements from a meteorological tower. The Smoke Week meteorological data were obtained from such a tower system as will be described later.

The above meteorological parameters are presented as required for fog-oil smoke in particular. Some smoke materials are hygroscopic in nature drawing water vapor from the atmosphere. For these smokes, the measurement of humidity is an important consideration.

PLUME DEFINITION

Ideally, one would want for each position experiencing the plume, a measurement of concentration distribution, i.e., a complete representation of the likelihood that a certain concentration value would be exceeded. Obtaining such a complete description is presently an impossible task, and thus, less complete data must be used. Since the primary interest lies in effects which occur either at or near the ground, the first simplification made is a choice of a standard measurement height, typically 0.5 - 1.5 m, as representative of ground-level effects. This is done despite the fact that significant near-ground gradients may exist.

The ideal scenario would be to employ real-time concentration monitors over a three-dimensional grid encompassing the region of plume impact. Such measurements over the time period in which smoke is present could provide a three-dimensional picture of the smoke density over time. In this way, the location and concentration of the densest portions of the plume would be known at all times based on data at a large number of plume cross-sections. In order to obtain the time histories of concentration needed to produce concentration distributions, fast responding instruments are required. Most often, optical instruments such as aerosol photometers serve this purpose. However, aerosol photometers sense total particulate levels and, thus, suffer from background concentration problems. In addition, aerosol photometers are better suited for relative rather than absolute concentration measurements.

At the opposite end of the application spectrum is the dosage sampler which is either a filter tube or a chemical impinger (bubbler). These aspirated devices collect smoke material from the air and, thus, provide a time-integrated. value of concentration, called a dosage. When properly used, the dosage sampler can provide highly reliable data down to very low levels, but yield no information on the fluctuation of concentraction during the sampling period.

In many of the Smoke Week experiments to be described in the next section, aerosol photometers are used in combination with dosage samplers, the latter being employed to provide absolute data by which to scale the relative measurements of the aerosol photometers.

Particle size distribution is a parameter of importance which can be measured using aerodynamic sizing techniques such as the cascade impactor or optical sizing techniques such as those based on laser light scattering. Comparison studies have shown that alternative methods of measuring particle size distributions do not always give the same results.

A parameter of fundamental importance in the assessment of potential environmental and human health impacts is deposition rate; unfortunately, no measurements of this type were made during the Smoke Week trials.

The smoke experiments described above should be carried out many times to cover different generator operating conditions. In this way, the variablilty of the ground-level concentrations and dosages can be determined.

In the following sections, a description of the measurement program carried out in Smoke Weeks III and IV is presented. As will be seen, some of

the data required above are not available. In the data descriptions to follow, this "ideal" program will be referred to for comparison purposes.

DESCRIPTION OF AVAILABLE DATA SETS

The most useful data for model validation studies come from Smoke Weeks III[2,3] and IV[4,5]. During these one week periods, one or two rows of aerosol photometer/chemical impinger pairs were placed downwind of the munition or smoke generator. These rows were approximately normal to the plume centerline within about 100 m of the source. Aerosol photometers (AP) measure concentration versus time through an optical scattering method. These instruments are rapid responding and, thus, are well suited for time-dependent concentration measurements, but their accuracy in terms of absolute concentration is poor. Thus, the AP readings were calibrated against measurements of dosage made simultaneously by the chemical impinger (CI), i.e., the readings were scaled on a time-by-time basis such that concentration dosages are equal for each AP/CI pair.

In Smoke Week III, for example, 42 aerosol photometers were used. Nine were located on the first line of sight (LOS1) and 32 were located on the second line of sight (LOS2); LOS1 and LOS2 were approximately normal to the centerline of the plume, and thus provided lateral concentration measurements of the plume at ground level at these two plume cross-sections. It should be recognized that these AP/CI instrument combinations have been used for many different types of smokes. The APs were used for all smokes. However, the CIs were used with the following obscurants: HC, fog oil, PEG 200, diesel fuel with additive, alkali chloride and phosphorous smokes. Alternative filter samplers were used instead of CIs for trials of single and dual obscurants involving the IR1, IR2, or IR3 obscurants. During Smoke Weeks III and IV, a special instrument pad was placed near the center of the sampling grid. Among the instruments it contained were an AP and particle sizers. A list of trials along with the availability of concentration and particle size data in Smoke Weeks III and IV follows.

SMOKE WEEK III...EGLIN AIR FORCE BASE, FLORIDA[2,3]

The site was at range C-52 of Eglin Air Force Base. Range C-52 has sandy soil, scattered pine trees and brush extended to an elevation of 16 m above ground level. Terrain in the vicinity of the 32-m meteorological tower was level and covered with grass, except for rutted roadways. Beyond the roadways there was a margin of grass with brush and small trees ranging from 0.5 to 3.0 m tall. At a distance of 300 m to the north, east, and south there was a thick pine forest 15-20 m tall on slightly rolling sand hills. Terrain variations over a characteristic path were used to determined surface roughness (Z_o). Roughness determination was complicated by wake effects, which can extend downwind for distances of 150 times the height of the obstacle. Z_o was estimated to be 0.5 m for the lower levels of the 32-m meteorological tower and 0.3 m for the upper levels.

A listing of munitions and obscurants used in Smoke Week III are presented in Table 1. The test site consisted of a range approximately 2 km square.

Figure 1 provides a sketch of the location of the different sampling devices used in the various experiments. Also shown in Figure 1 is the position of the 32-m meteorological tower and five 2-m meteorological masts. A typical location of the emission source was 100 m normal and to the left of center of the two instrument rows.

The sampling devices used are listed below:

a. For aerosol sampling, 42 aerosol photometers (APs), 2 particle size analyzers (PSAs) and 128 aerosol samplers [chemical impingers (CIs) and filter samplers] were used. The main sampling line (along LOS 2) consisted of 101 aerosol samplers (≃ 3 m apart) and 33 APs (≃ 9 m apart) as shown in Figure 1. The auxiliary sampling line consisted of 27 aerosol samplers (≃ 6 m apart) and 9 APs (≃ 18 m apart) (Figure 1). Hi-volume samplers for dust aerosols were located along both sampling lines; 17 along the main sampling line (≃ 24 m apart) and nine along the auxiliary sampling line (≃ 18 m apart) (Figure 1). The particle size sampling was done near the center of the main sampling line (LOS 2).

b. The APs monitored the obscurant concentration for all tests except those with IR1, IR2, and IR3.

c. CIs and filter samplers were placed along the sampling lines to measure the dosage of obscurant during the sampling period.

d. The PSAs were located near the center of the main sampling line (on the instrument cluster), approximately 1.5 m above ground level.

Meteorological data acquired were largely from a 32-m meteorological tower located at the center of the test grid and equipped to measure the following:

(1) horizontal/vertical wind directions at the 2, 4, 8, 16, and 32-m levels,

(2) horizontal wind speed at the 2, 4, 8, 16, and 32-m levels,

(3) temperature and dew point at the 2 and 32-m levels, and

(4) temperature difference between the 0.5 and 4-m levels.

In addition, four 2-m meteorological masts located along the main sampling line (Figure 1) were equipped to measure horizontal wind direction and wind speed.

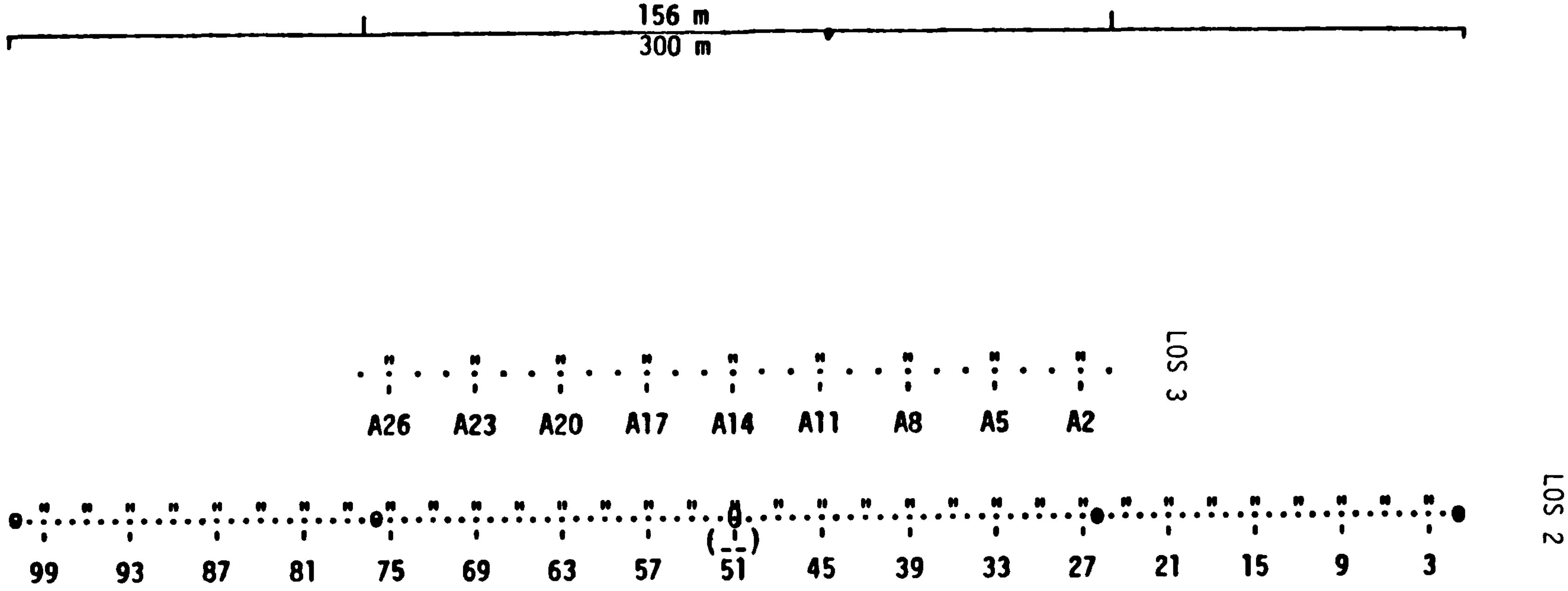
On the 32-m meteorological tower, the horizontal and vertical components of the wind direction were monitored with a bivane, a dual-axis wind vane that measures horizontal wind direction in angular degrees relative to true North and the vertical wind direction ("elevation") in angular degrees relative to the horizontal. The wind speed was monitored by a 3-cup anemometer assembly.

For the purpose of estimating the Pasquill stability class, the solar azimuth, altitude and radiation data were acquired. Atmospheric stability is given in Pasquill categories and Bulk Richardson number (BU). Pasquill

TABLE 1. SUMMARY OF FIRING/TRIAL DATA FOR SMOKE WEEK III AT EGLIN AFB, FL....From Nelson and Farmer 1981[2]

Date (1980)	Time (EDT)[a]	Trial Number	Obscurant	Munition	Quantity
11 Aug	0927	1	RP	L8A1 Grenades	6
11 Aug	1209	2	Fog Oil	XM49 Generator	N/A
11 Aug	1339	3	Diesel w/Additive	XM49 Generator	N/A
11 Aug	1537	4	Fog Oil	M3A3 Generator	N/A
11 Aug	1649	5	PEG 200	XM49 Generator	N/A
11 Aug	1748	6	Fog Oil w/IR1	XM49 Generator	N/A
12 Aug	0813	7	PWP	5 In Zuni	1
12 Aug	1019	8	Fog Oil	M3A3 Generator	N/A
12 Aug	1456	9	HC	155 mm Canisters	24
12 Aug	1619	10	IR3	XM49 Generator	N/A
12 Aug	1721	11	IR1	XM49 Generator	N/A
13 Aug	1000	12	Diesel	VEESS	N/A
14 Aug	1654	13[b]	Diesel	VEESS	N/A
14 Aug	1806	14	IR2	XM49 Generator	N/A
14 Aug	1846	15	PEG 200	XM49 Generator	N/A
15 Aug	1341	16	WP	XM825	2
15 Aug	1510	17	HC	155 mm Canisters	24
15 Aug	1545	18	RP	CBU 88	1
15 Aug	1645	19	Fog Oil	XM49 Generator	N/A
15 Aug	1742	20	IR2	XM49 Generator	N/A
16 Aug	0748	21	WP	2.75 In Rockets	12
16 Aug	1350	22	HC	155 mm Canisters	1
16 Aug	1507	23	RP	M8 Grenades	6
16 Aug	1536	24	PW	5 In Zuni	3
16 Aug	1646	25	WP	XM825	2
16 Aug	1747	26	IR1	XM49 Generator	N/A
18 Aug	1046	27	IR1	Experimental Grenades	10
18 Aug	1249	28	Dust	105 mm HE Equivalent[c]	N/A
18 Aug	1453	29	Dust	Vehicular	N/A
18 Aug	1726	30	RP	CBU88	1
19 Aug	1143	31	IR2	Experimental Grenades	12
19 Aug	1503	32	WP	XM825	4
19 Aug	1723	33	WP	122 mm Foreign	6
19 Aug	1825	34	Alkali Chloride	Experimental Smoke Pot	1
20 Aug	1031	35	IR2	Grenades	24
20 Aug	1124.8	36	Alkali Chloride	Experimental Smoke Pot	4
20 Aug	1331	37	Dust	155 mm HE[c]	N/A
21 Aug	0905	38	IR1	M76 Grenades	12
21 Aug	0942	39	RP and IR2	L8A1 Grenades/M76 Grenades	12/1
21 Aug	1021	40	RP and IR2	L8A1 Grenades/M76 Grenades	6/6
21 Aug	1109	41	Fog Oil/IR1	"Smokey Bear"[d]	N/A
21 Aug	1133	42	Fog Oil/IR2	"Smokey Bear"	N/A

a. Eastern Daylight Time.
b. No data were collected by DPG due to malfunction of data acquisition system.
c. Statically detonated explosives to represent the explosive properties of a High Explosive (HE) round.
d. Experimental method for generating smoke.



A Positions numbers for auxiliary sampling line
· Aerosol samplers
' Dust samplers
" Aerosol photometers
() Particle size instruments (PSA)
- Millipore filter
o 2-meter meteorological mast
O 32-meter meteorological tower with vertical transmittance

[30 m]

Figure 1. DPG sampler array for Smoke Week III at Eglin AFB, FL ....From Nelson and Farmer 1981.[2]

stability categories were determined using the Turner method[6] based on wind speed and solar radiation index, modified by cloud cover and cloud height. The 0.5 to 4.0-m BU is a nondimensional stability parameter which is primarily a function of the ratio of temperature lapse to the squared wind speed. BU calculations are available for Trials 7-12 and 14-42 where valid meteorological measurements were made. Positive values indicate stable meteorological conditions and negative values indicate unstable conditions. During the test period, the Pasquill stability categories varied from A to D (51 percent in the C category, 32 percent B, 12 percent D, and 5 percent in the A category). The average relative humidity was 70 percent with a minimum and maximum of 54 and 100 percent, respectively. Eighteen of the trials involved hygroscopic smokes. Two (11 percent) of the hygroscopic smoke trials were conducted at a relative humidity greater than 85 percent, six (33 percent) greater than 80 percent, ten (56 percent) greater than 70 percent, and 16 (89 percent) were conducted at a relative humidity greater than 60 percent.

SMOKE WEEK IV... U. S. ARMY REDSTONE ARSENAL, HUNTSVILLE, ALABAMA[4,5]

These tests were conducted at Test Area 1 (TA-1) at Redstone Arsenal. TA-1 is a relatively flat, open field approximately 6 km long and 1-2 km wide. The site elevation is 170 m above sea level, but only 1 m above the local water table. Consequently, part of the test area was damp, and the lowest areas contained pools of water. Road beds across the grid are built up 1 m above field level.

TA-1 is surrounded by dense hardwood forest. Tree height is typically 10 m. The closest major terrain obstacle is Bradford Mountain, rising 70 m above the local terrain, 5 km west of grid center. Table 2 lists the munitions and obscurants used in the tests at Redstone. In this series of tests, only one aerosol sampling line was used, associated with LOS 1 of the total of four optical lines of sight. Figure 2 provides a sketch of this line of sight along with the sampling line, instrument trailer (MMU) and 45-m meteorological tower.

Table 3 lists the samplers used for plume characterization in Smoke Week IV. A short description of the relevant sampling devices follows.

a. Forty-two aerosol photometers (APs), one particle size analyzer (PSA), and 12 aerosol samplers (ASs) [chemical impingers (CIs) and/or filter samplers] were used for obscurant sampling (Table 3). Samplers were positioned at five points along LOS 1 and on the mobile measurement unit (MMU), 1.5 m above ground level. The sampling line had five pairs of AS's at five positions and 33 APs at 9-m intervals. Particle size sampling was done at the MMU near the center of the sampling line (Figure 2).

b. APs monitored the obscurant concentration versus time along LOS 1 and at eight locations on the meteorological tower. The APs were not used during the release of IR obscurants and recorded only relative concentrations for multiple obscurant trials.

TABLE 2. SUMMARY OF FIRING/TRIAL DATA FOR SMOKE WEEK IV AT REDSTONE ARSENAL, AL....From Burgess and Nielsen 1982[5]

Date (1980)	Time (EDT)	Trial Number	Obscurant[a]	Munition[b]	Quantity
2 Nov	2122	1	HE Dust	155 mm	3
2 Nov	2207	2	"Arizona Road" Dust	"Mitey Mite" Generator	3
3 Nov	1408	3	Fog Oil	M3A3	1
3 Nov	1454	4	Diesel Oil	VEESS	1
3 Nov	1605	5[c]	Fog Oil & IR2	MARS Generator	1
3 Nov	1853	6	Fog Oil	Generator	1
3 Nov	1942	7[d]	Diesel Oil & Additive (Brock)	Generator	1
3 Nov	2024	7A	Diesel Oil & Additive (Brock)	Generator	1
3 Nov	2123	8	RP	L8A1 Grenades	8
4 Nov	1401	9	PWP	5 In Zuni	1
4 Nov	1508	10	PWP	5 In Zuni	3
4 Nov	1701	11	RP (Wedges)	81 mm	3
4 Nov	1757	12	RP (Wedges)	81 mm	6
4 Nov	1905	13	WP (Wedges)	155 mm	2
4 Nov	2011	14	WP (Wedges) & Flare	155 mm Flares	2/2
4 Nov	2130	15	IR2	IR Grenades	8
5 Nov	1503	16	HC	M116 (155 mm)	6
5 Nov	1813	17[e]	"Arizona Road" Dust	"Mitey Mite" Generator	3
5 Nov	1939	18	Fog Oil & IR2	"Smokey Bear"	1
5 Nov	2115	19	SCIR	Grenades	2
5 Nov	2147	20	RP & IR2	IR2/L8A1 Grenades	4/4
5 Nov	0131	21	WP (Wedges)	155 mm	2
5 Nov	0311	22	WP (Wedges)	155 mm Flares	2/3
5 Nov	1623	23	Dust, RP, Diesel Oil	"Mitey Mite"/L8A1/VEESS	3/12/1
6 Nov	1713	24	Dust, Fog Oil	"Mitey Mite'/M3A3	3/1
6 Nov	1817	25	RP	CBU 88 Canisters	3
6 Nov	1959	26	Developmental IR	Foreign IR Grenades	8
6 Nov	2047	27	Fog Oil & IR2	MARS Generator	1
6 Nov	2221	28	RP & IR2	L8A1/IR Grenades	6/5
7 Nov	1433	29	IR 2	IR2	12
7 Nov	1514	30	SCIR	Grenades	2
7 Nov	1608	31	IR2	IR2/Flare	8/1
7 Nov	1714	32	Developmental IR	Foreign IR Grenades	12
7 Nov	1759	33	RP & IR2	L8A1/IR2	4/4
7 Nov	1838	34	Anthracene	OTD Candles	8
7 Nov	2021	35	RP	CBU88 Canisters	3
7 Nov	2158	36	Dust, RP, Diesel Oil	"Mitey Mite"/L8A1/VEESS	3/12/1
9 Nov	1427	37	HE Dust & WP	155 mm/XM825	3/2
9 Nov	1754	38[f]	Fog Oil	Generator	2
9 Nov	1824	39[g]	IR2	Generator	1

a. HE = high explosive; IR2 = infrared obscurant, type 2; RP = red phosphorus;
PWP = plasticized white phosphorus; SCIR = a type of infrared obscurant; IR = infrared; WP = white phosphorus.

b. CBU = Cluster Bomb Unit; OTD = supply of candles from Office of Test Directorate, White Sands Missile Range; VEESS = Vehicle Exhaust Emission Smoke System.

c. No data collected on this test.

d. Emergency landing of helicopter caused early shutdown of lasers and smoke disseminator. Test repeated as test 7A. OPM Smk/Obs requested that DPG process data from both trials.

e. Wind shift at approximately Z+2 min. caused cloud to move from generators across LOS 3 and off the grid; designated "poor test".

f. Wind shift caused cloud to lift above sampler line; designated "poor test."

g. Light and variable winds resulted in poor cloud build-up and travel; designated "very poor test".

c. The PSA was located in the MMU center. PSA data were recorded on magnetic tape for particle diameters from 0.03 to 10 microns in 15 size ranges, with one range for particles greater than 10 microns in diameter.

d. All sampling equipment were activated at least two minutes before firing for each trial (Z-2 min) to record background levels (munitions function time was designated Z-time).

e. Control CIs were used in each trial for field laboratory quality control. The control samplers were aspirated at the same rate as the samplers on the line, but were outside the smoke cloud.

f. CIs and charcoal tubes connected in series were used on all fog oil and diesel fuel trials. The flow rate of this sampler combination averaged 6.9 ℓ/min.

g. The Gelman filter samplers were used on all trials of single and dual obscurants involving IR obscurants. The 7.2 ℓ/min orifices were used in all Gelman filter samplers. After each trial, Gelman filters were removed from their holders and placed in capped test tubes for analysis.

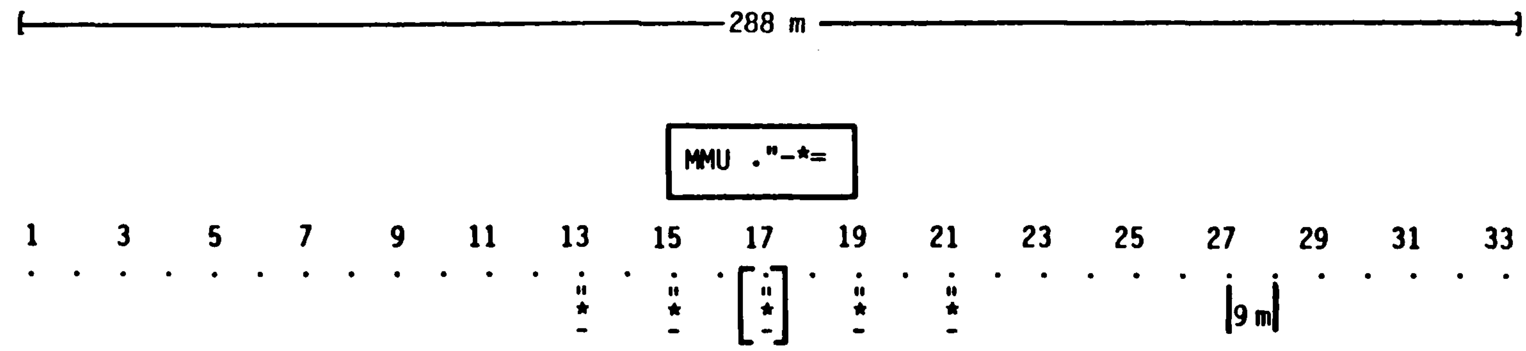
h. Dust samplers were calibrated on site to operate at 50 cfm. The filters were weighed before and after each trial.

i. The contents of the samplers were analyzed for the principal chemical element of the obscurant. Aerosol values ($mg{\cdot}min/m^3$) were computed using the appropriate yield factor, sampler efficiency, and sampler flow rates. Data from the control sampler was reviewed and used to determine background levels.

TABLE 3. SAMPLERS FOR CLOUD CHARACTERISTICS - SMOKE WEEK IV ....From Burgess and Nielsen 1982[5]

Sampler Type	Location[a] LOS 1	MMU	45-m Tower	Sampling Rate (ℓ/min)	Notes
Aerosol sampler (CIs)	10	2	-[b]	6.9	Controls (2)
Aerosol photometers	33	1	8	28	
Particle size instruments	-	1	-	0.07	1.5-m level
Gelman filters (25 mm)	10	2	-	7.2	Controls (2)
Dust samplers (DSs)	5	-	-	1416	1416 ℓpm, Controls (2)

a. See Figure 2.
b. Sampler not used at this location.



. Aerosol Photometer (AP)
" Chemical Impinger (CI)
- Filter Sampler (FS)
* Dust Sampler (DS)
[] 45-m Tower
= Particle Size Analyzer (PSA)
▭ Mobile Measurement Unit (MMU)

NOTE: Eight APs on 45-m tower at following levels:

m Above Ground Level	Top of Tower Section No.
3.7	2
7.4	4
11.1	6
14.8	8
18.5	10
22.2	12
32.0	17
43.9	24

Figure 2. DPG sampler array (LOS 1) for Smoke Week IV
....From Nelson et al. 1982.[4]

j. Concentration length (CL) values were calculated by two methods: (1) using DPG mass extinction coefficients and instantaneous values of transmittance for wavelength 3.4 μm and (2) using AP concentration readings by integration over the line of sight. Both methods were used to calculate CL values for LOS 1.

k. APs measured concentration values (mg/m^3) along the sampling line along LOS 1. Concentration values are reported for all trials except those containing IR-type obscurants. APs were not used on IR trials because they have a limited response to IR-type obscurants.

l. Particle size measurements were made with a Climet PSA located in the MMU near the center of the test grid. The PSA measures particle diameters from 0.03 to 10 μm in 15 size ranges, with one range for particles greater than 10 μm in diameter. PSA measurements are available for trials, as noted in the table of data availability status (see Table 4). These data are presented as trial-averaged proportions (of the total counted) per particle size range and the computed particle size distribution (PSD) moments including an estimate of the average number density (number of particles/cm^3).

Relevant meteorological measurements were as follows:

a. A 45-m meteorological tower was located at station 17 of the center sampling line (LOS 1) (Figure 2) and was equipped to measure the following:

(1) Temperature and dew point at the 2 and 32-m levels

(2) Temperature at the 0.5, 2, 4, 10, 16, 32, and 45-m levels

(3) Horizontal components of wind direction and speed at the 2, 4, 10, 16, 32, and 45-m levels

(4) Vertical component of wind direction at the 10 and 32-m levels

b. Copies of Weather Bureau-Army/Navy (WBAN) weather observation forms were obtained from the nearest weather station to provide hourly measurements of precipitation, barometric pressure, ambient cloud coverage (percent), and ambient visibility. The position of the sun at the time of munition detonation was calculated using the DPG Pasquill Stability and Sun Routine (PSSR) program.

c. Atmospheric stability is given in Pasquill categories, determined from sky condition and the 10-m wind speed using Turner's objective method.[6] During the test, the Pasquill stability categories varied from B to F, with 45 percent in category C, 40 percent in category D, 7.5 percent in category B, 5 percent in category F (the two night trials), and 2.5 percent in category E (near sunset). The psychrometric relative humidity (RH) ranged from 32 to 95 percent, with a mean trial-averaged RH of 57 percent.

Table 4 lists the availability of test data for each of the 39 trials. Table 5 lists the samplers used for each type of obscurant in Smoke Week IV.

TABLE 4. DPG SMOKE WEEK IV TEST DATA AVAILABILITY
....From Burgess and Nielsen 1982[5]

Trial Number	AP	PSD	Met	Sun Sky
1	X	–	X	X
2	X	–	X	X
3	X	?	X	X
4	X	?	X	X
5	–	–	–	–
6	–	?	X	X
7	X	–	X	X
7A	X	–	X	X
8	X	–	X	X
9	X	?	X	X
10	X	?	X	X
11	X	?	X	X
12	X	?	X	X
13	X	?	X	X
14	X	?	X	X
15	N	–	X	X
16	X	?	X	X
17	X	?	X	X
18	N	–	X	X
19	N	–	X	X
20	N	–	X	X
21	X	?	X	N
22	X	?	X	N
23	X	?	X	X
24	X	?	X	X
25	X	?	X	X
26	X	?	X	X
27	–	?	X	X
28	X	?	X	X
29	N	N	X	X
30	N	N	X	X
31	N	N	X	X
32	N	N	X	X
33	N	N	X	X
34	X	?	X	X
35	X	?	X	X
36	X	?	X	X
37	X	?	X	X
38	X	?	X	X
39	N	N	X	X

X = Data Available
– = No Data
? = Questionable Data
N = Not Required

TABLE 5. SAMPLERS USED FOR EACH TYPE OBSCURANT - SMOKE WEEK IV ....From Burgess and Nielsen 1982.[5]

Trial Number	Source[a]	Samplers Used[b]
1	HE Dust 155 mm	AP, PSA, DS
2	Dust Generator	AP, PSA, DS
3	M3A3 Generator	AP, PSA, CI
4	VEESS M60/48	AP, PSA, CI
5	Fog Oil & IR2	No Data
6	Generator	AP, PSA, CI
7A	Generator	AP, PSA, CI
8	L8A1 Grenades	AP, PSA, CI
9	5 In Zuni	AP, PSA, CI
10	5 In Zuni	AP, PSA, CI
11	81 mm	AP, PSA, CI
12	81 mm	AP, PSA, CI
13	155 mm	AP, PSA, CI
14	155 mm & Flares	AP, PSA, CI
15	IR2 Grenade	GF, DS
16	HC 155 mm	AP, PSA, CI
17	Dust Generator	AP, PSA, DS
18	Smokey Bear & IR2	CI, GF
19	SCIR Grenades	GF, CI
20	IR2 & L8A1	GF, CI
21	155 mm	AP, PSA, CI
22	155 mm	AP, PSA, CI
23	VEESS & Dust & L8A1	AP, CI, DS
24	M3A3 & Dust	AP, PSA, CI, DS
25	CBU 88	AP, PSA, IC
26	Foreign IR Grenades	AP, PSA, CI
27	MARS Generator	AP, PSA, CI
28	IR2 & L8A1	GF, DS
29	IR2	GF
30	SCIR Grenades	GF, CI
31	IR2 & Flare	GF, DS
32	Foreign Grenades	None
33	IR2 & L8A1	CI, GF
34	Anthracene OTD Candles	AP, PSA, GF
35	CBU 88	AP, PSA, CI
36	VEESS & Dust & L8A1	AP, CI, DS
37	155 mm Dust	AP, PSA, CI, DS
38	Generator	CI
39	MARS Generator	GF, DS

a. See Table 2 footnotes for explanation of munitions.

b. AP - Aerosol Photometer
PSA - Particle Size Analyzer
DS - High Volume Dust Sampler
GF - 25 mm Gelman Glass Fiber Filter
CI - Chemical Impinger

SAMPLE DATA SET--SMOKE WEEK III, TRIAL 4

In total, there are seven fog oil trials in Smoke Weeks III and IV. For Smoke Week III, these are Trials 2, 4, 8, and 19; for Smoke Week IV, there are Trials 3, 6, and 38. The most complete dataset available for model testing is the M3A3 release of fog oil during Trial 4 of Smoke Week III. The other six trials will be discussed briefly later.

The array of aerosol photometers and chemical impingers used in that trial is given in Figure 3. Each AP/CI pair is represented by a dot. As may be seen, the far line of monitors is only about 100 m away from the source. The near line of monitors is approximately 60 m away from the smoke generator. Clearly, the far line of monitors is better able to resolve the plume than the near line of monitors due to the fact that monitor spacing is less. For this test, the fog oil was released from the smoke generator at a height of 2 m and the release rate was constant over a duration of about five minutes. One-second average concentrations were observed by aerosol photometers on the two lines of monitors. The time series of concentration observations at each monitor illustrate both meandering (intermittency) and in-plume fluctuations, as shown in Figure 4. When the plume is present at the monitor, it is highly turbulent.

Figure 5 shows the crosswind variation of the concentration statistics over the far line of monitors for Trial 4. Because the "plume" does have a begining and an end in these trials, the data may be considered only from the time marking the first significant impact (concentration, C, greater than 15 mg/m^3; see Figure 4) anywhere on the are to the time marking the last impact.[7] Also, because spurious values of C equal to 1 or 2 appeared randomly during the "clean air" periods, Hanna defined a threshold of 3 for plume intermittency (I) calculations.[7]

Figure 5 contains observed values of $\bar{C}$, $\sigma_c/\bar{C}$, and I. In this figure,

$\bar{C}$ = mean value of the concentration time series at one point,
σ_c = standard deviation of the concentration time series at one point, and
I = intensity of short time average concentration fluctuations, $\sigma_c/\bar{C}$.

An effective σ_y for the mean concentration curve of about 18 m was found for Trial 4. It is interesting that intermittency I equals only about 0.5 to 0.6 at the center of the mean plume. That is, the plume is absent almost half the time on the mean plume centerline. At crosswind distances of two standard deviations from the center of the mean plume, the plume is absent over 90% of the time. The variation of concentration fluctuation intensity, $\sigma_c/\bar{C}$, is fairly smooth in this trial, ranging from about 1.3 on the mean plume centerline to about 4 to 5 at crosswind distances of two standards deviations. The crosswind integrated (CWI) concentrations were also analyzed for this arc, giving $\sigma_c/\bar{C}$(CWI) equal to 0.80 for Trial 4 (Ref. 7). This number is less than that for the point observation because the variation in the y direction has been averaged out.

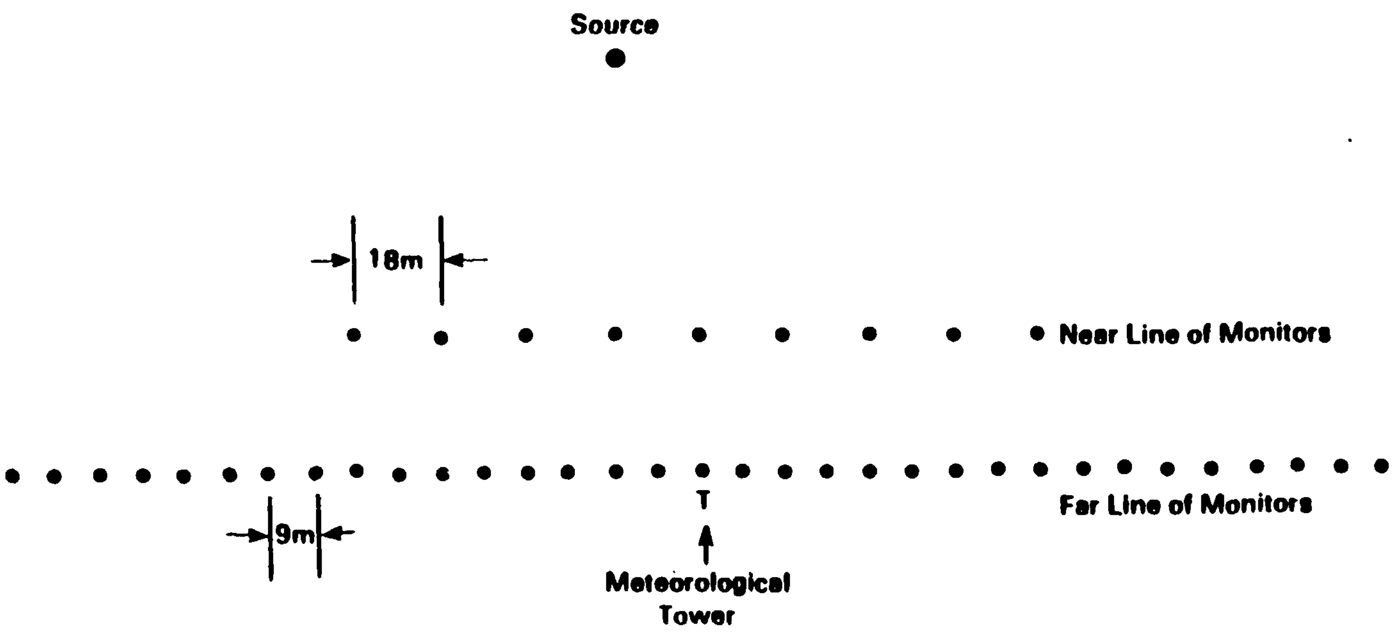


Figure 3. Monitor array and source location for Smoke Week III, Trial 4 experiment....From Hanna 1984.[7]

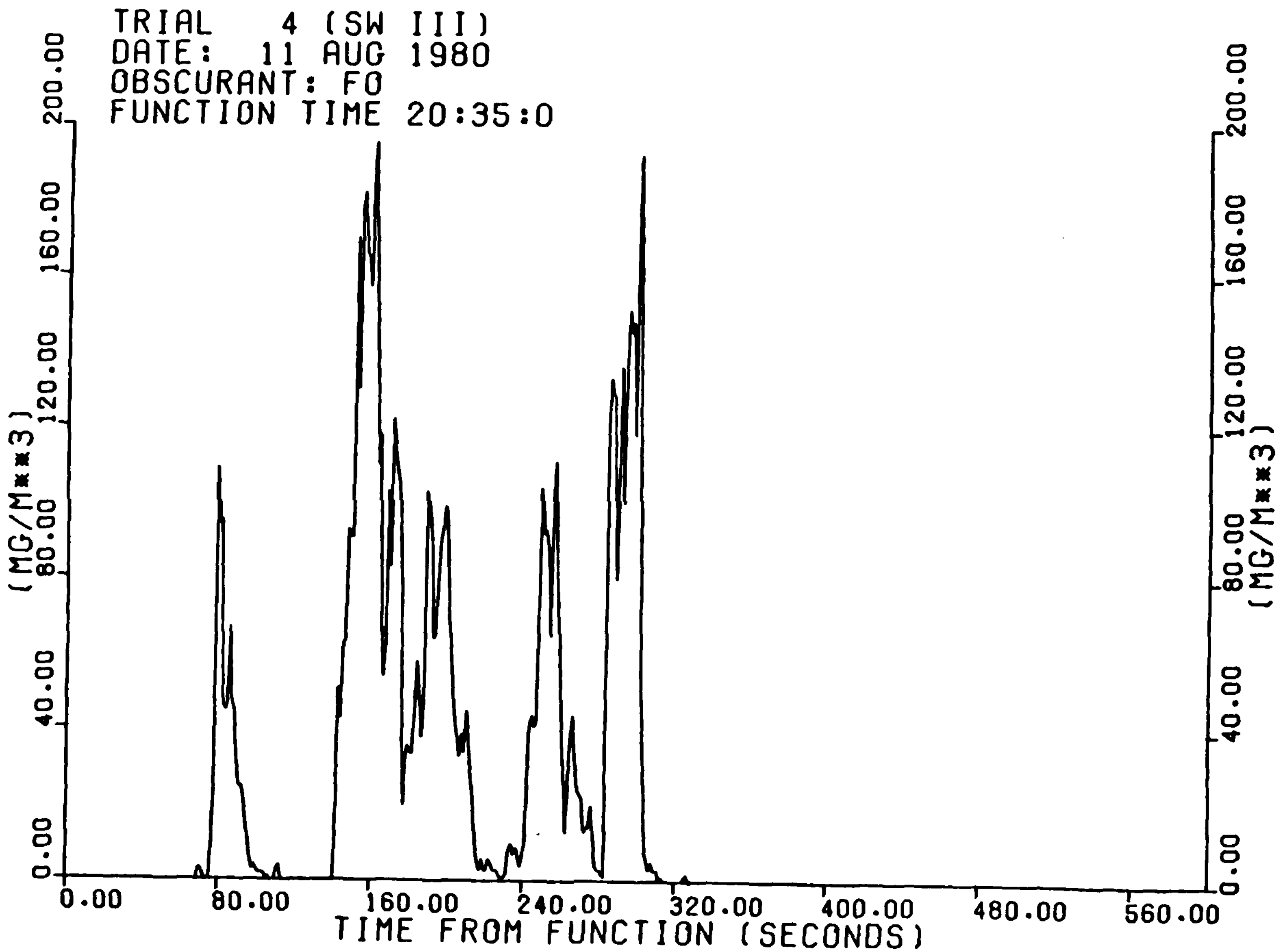


Figure 4. Time series of concentration for a monitor near the mean plume center in Trial 4 of Smoke Week III....From Nelson and Farmer 1981.[2]

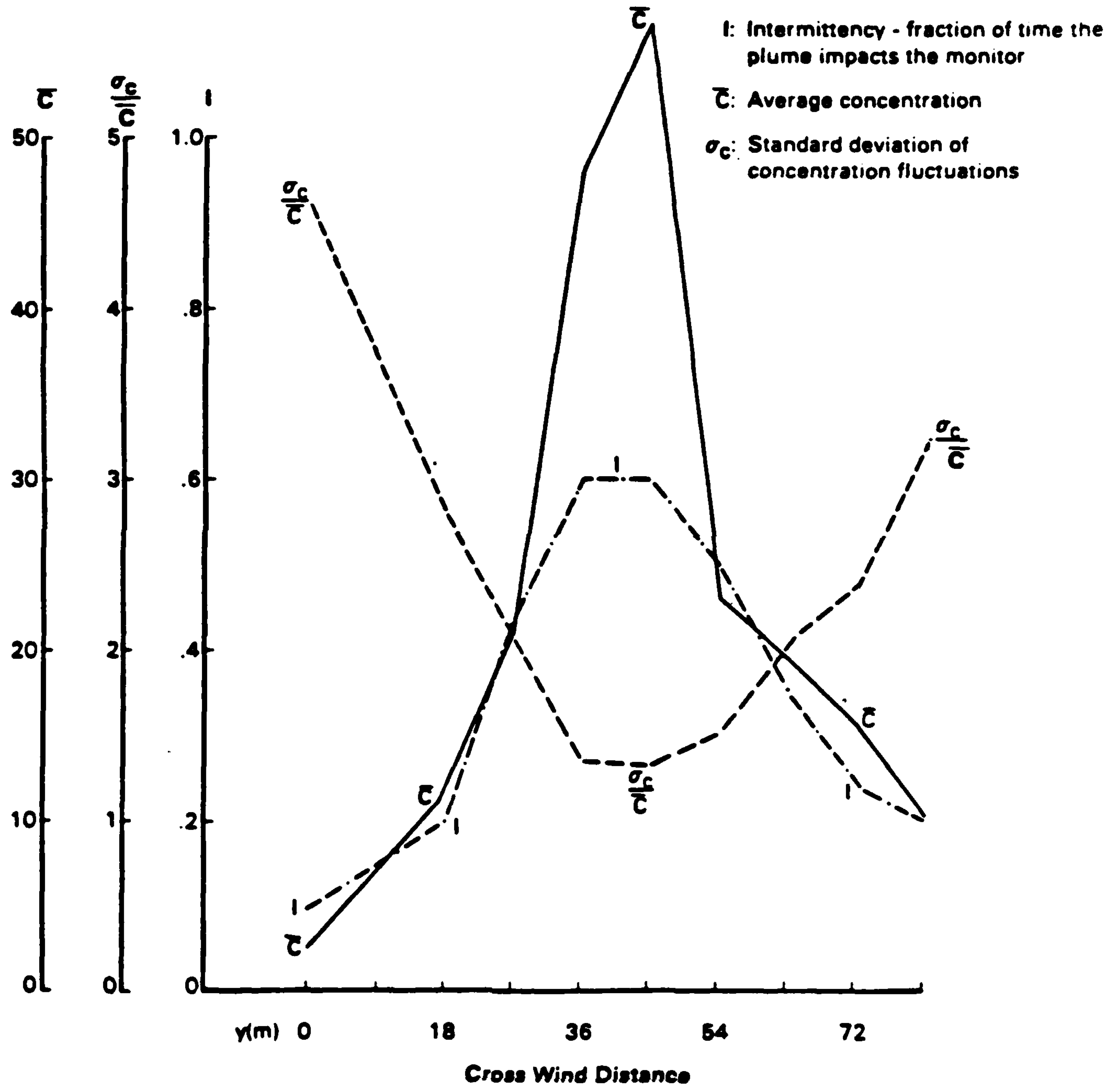


Figure 5. Smoke Week III Trial 4 observations of $\bar{C}$, $\sigma_c/\bar{C}$, and I ....From Hanna 1984.[7]

The following meteorological observations were made on a small tower near the middle of the far line of monitors.

	u(2m)	σ_θ(2m)	Pasquill Class
Trial 4	4.1 m/s	13°	C

Sampling times were the same as those for the monitoring data.

Measurements of concentration as a function time for the entire LOS 2 is given in Figure 6. Note that most of the samplers were not affected by the plume and that periods of intermittency occur for samplers that do register concentrations above zero.

The coordinates of the AP/CI pairs are known with respect to the center of the test grid (taken as the origin). Table 6 provides the positions of the 2-m meteorological stations and the relevant instruments in the instrumentation pad with respect to the pad origin. The coordinates of all AP/CI pairs and the smoke generator are also known but were not presented here due to space considerations.

The relative orientation of the two sampling rows, the fog oil generator and wind speed/direction is given in the top diagram in Figure 7. Dosages measured from the AP/CI system at LOS 2 and LOS 3 are given in the diagram at the bottom of Figure 7. Note the Gaussian shape of each lateral profile. The slight shift in location of the peak concentration is likely due to lateral shifts in the wind between LOS 2 and LOS 3. More detailed diagrams of the dosages in LOS 2 and LOS 3 are given in Figure 8. These data are the most most useful in model testing. However, both profiles are located very close to the fog oil generator. A discussion of the quality of the data of the type as in Figure 8 will be discussed in the next section.

Table 7 lists a summary of the averages of the meteorological variables measured during the period of operation of Trial 4. Vertical profile data are presented from the 32-m meteorological tower in the table as well as wind speed and direction from the four 2-m towers.

All the particle size instrumentation are contained within the University of Tennessee Space Institute (UTSI) instrumentation cluster (see Figure 2). Table 8 presents a summary of the instruments that are relevant to our program. These instruments are divided into two categories: concentration measurement devices and particle sizing devices. The location of the various instruments (including others not listed in Table 8) are given in Figure 9. The coordinates of each instrument are known with respect to the pad as well as with respect to the smoke generator (see Table 9 for coordinates with respect to pad). Figure 4 presented concentration versus time for the aerosol photometer placed within the instrument cluster. A discussion of the sampling problems that have occurred with these data is presented later. The overall quality of the particle size data is discussed in a short summary of those data that follows.

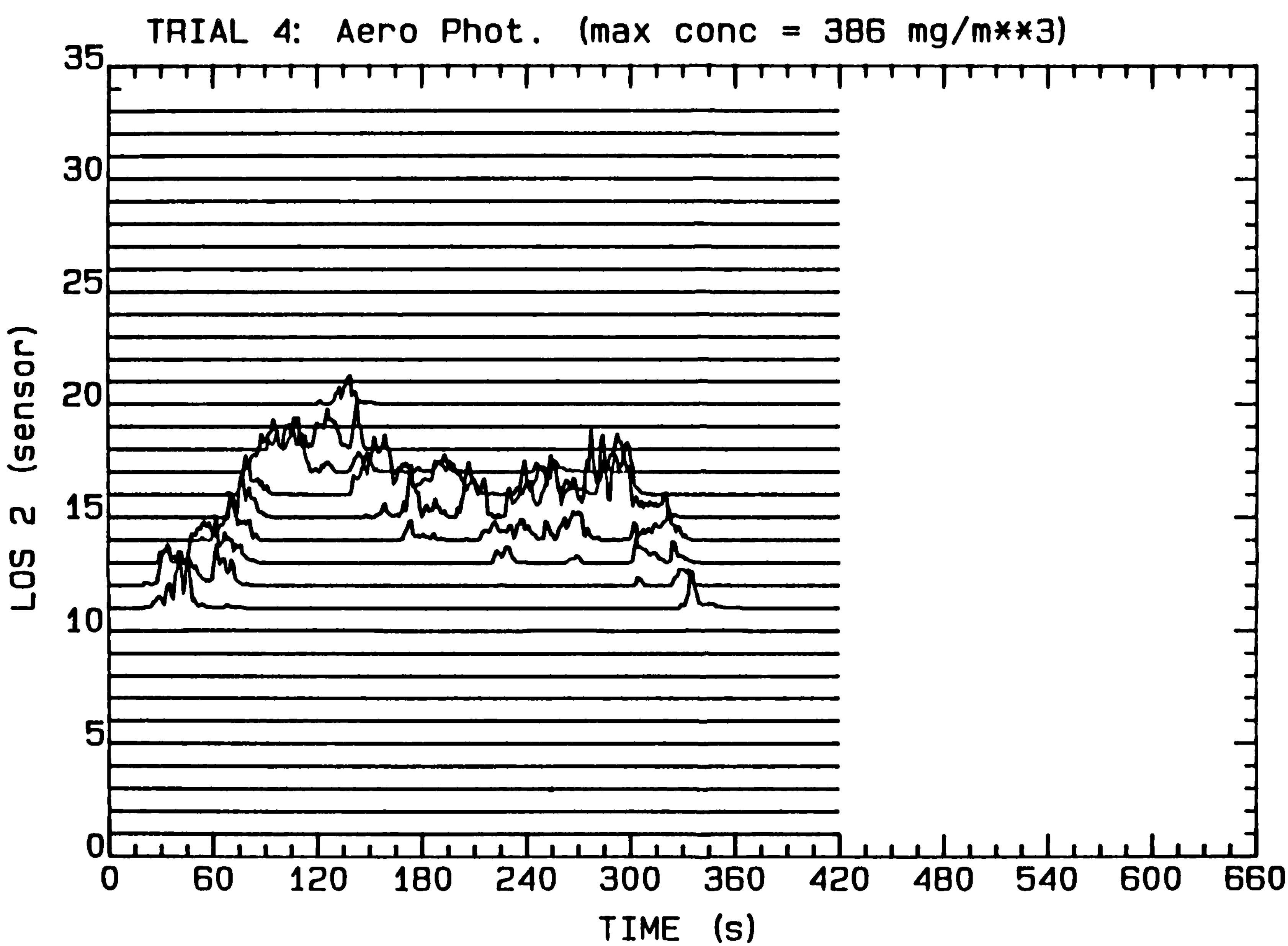


Figure 6. Concentration as a function of time for all samplers on LOS 2 for Trial 4, Smoke Week III....From Farmer.[8]

TABLE 6. LOCATION OF METEOROLOGICAL INSTRUMENTATION AND AUXILIARY SAMPLING INSTRUMENTS, SMOKE WEEK III ....From Nelson and Farmer 1981[2]

	X(m)	Y(m)	Z(m)
Particle Size Analyzers Nos. 1 and 2 (in Instrumentation Pad)	-7.94	3.38	1.70
Aerosol Photometer (in Instrumentation Pad)	-5.02	3.92	1.90
Solar Radiation	-359.00	6.10	5.0
		Meteorological	
	X(m)	Y(m)	Z(m)
		32-m Tower	
2-m level	5.19	0.1	2.19
4-m level	5.19	0.1	4.19
8-m level	5.19	0.1	8.19
16-m level	5.19	0.1	16.19
32-m level	5.19	0.1	32.19
		2-m Tower	
@Sampling Station 26	-73.37	-0.25	1.98
@Sampling Station 76	75.02	-0.17	1.79
@Sampling Station 101	151.80	-0.05	1.80

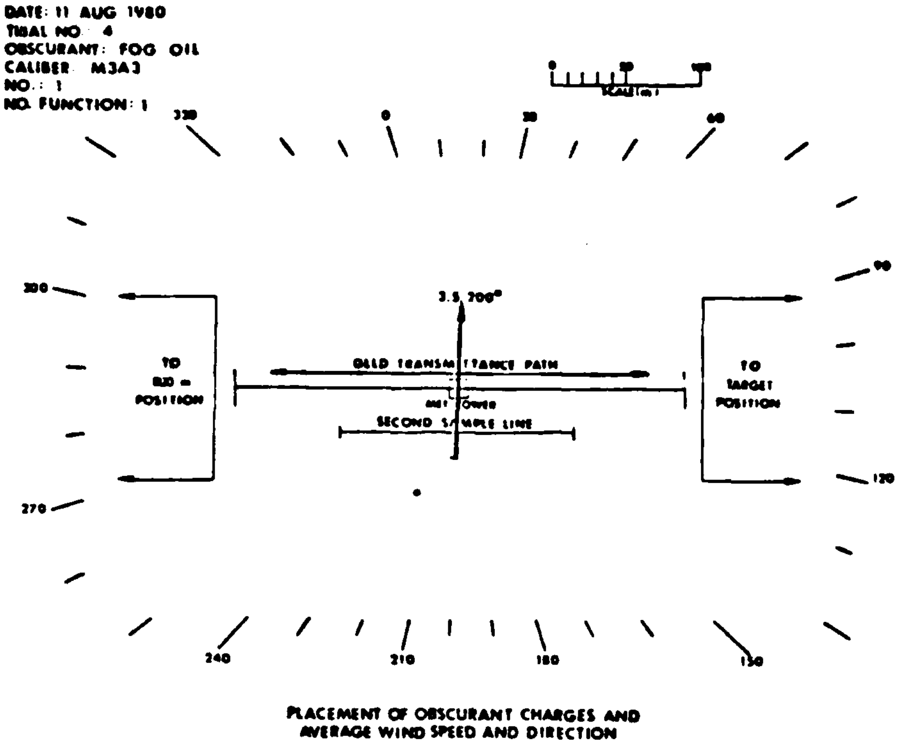


Figure 7a. Orientation of the two sampling rows, smoke generator, and wind speed/direction for Trial 4, Smoke Week III....From Nelson and Farmer 1981.[2].

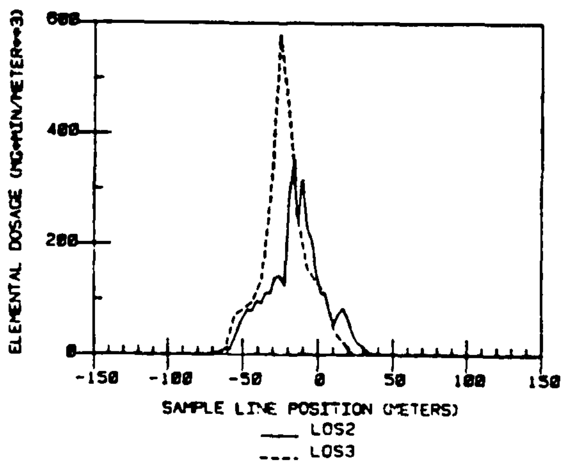


Figure 7b. Concentration dosage measured as a function of lateral distance on LOS 2 and LOS 3 for Trial 4, Smoke Week III....From Nelson and Farmer 1981.[2]

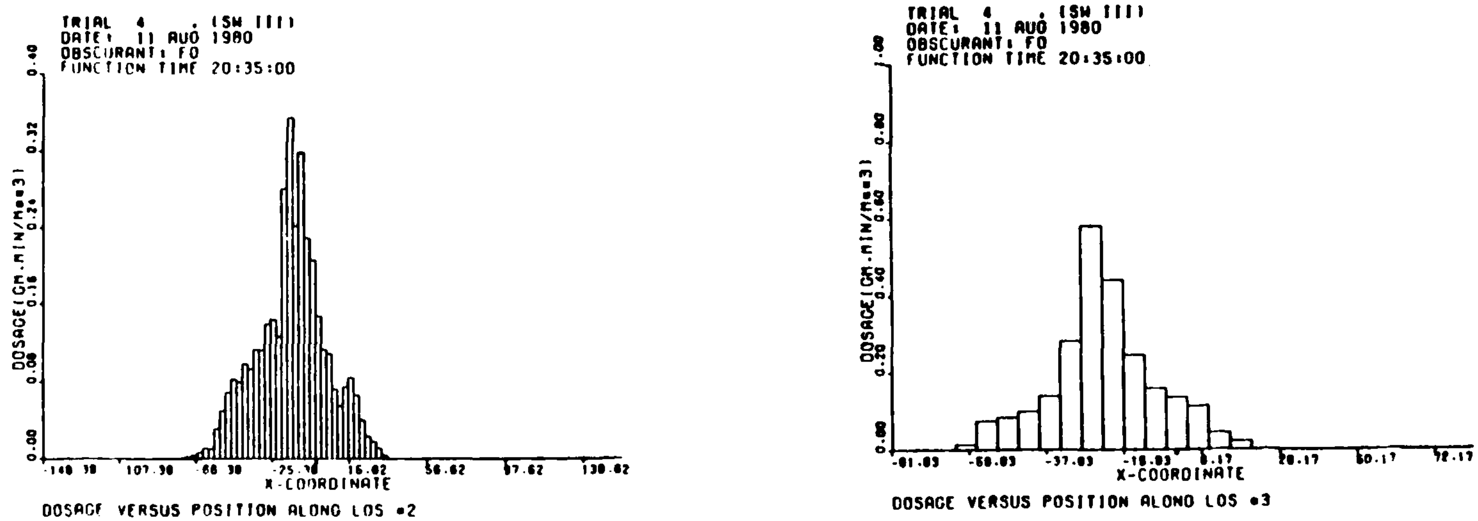


Figure 8. Concentration dosages measured along LOS 2 and LOS 3 over the period of Trial 4, Smoke Week III....From Nelson and Farmer 1981.[2]

TABLE 7. SUMMARY OF METEOROLOGICAL DATA MEASURED FOR TRIAL 4, SMOKE WEEK III....From Nelson and Farmer 1981[2]

SUMMARY OF TEST DAY DATA

Trial: 4
Date: 11 Aug 1980
Time: 20:35:00 to 20:42:00 (DPG)
Obscurant: Fog Oil

Trial Averaged Meteorological Tower Data

	Level, Meters				
Parameter	2.0	4.0	8.0	16.0	32.0
Wind Speed (m/sec)	4.12	4.59	4.89	5.21	5.66
Wind Direction (degrees)	206	201	206	204	217
Horizontal Std. Dev. (degrees)	13.2	12.6	10.6	8.4	6.9
Vertical Std. Dev. (degrees)	6.1	6.0	6.1	6.2	6.9
Ambient Temp. (degrees C)	30.9	M	NR	NR	30.1
Dew Point (degrees C)	22.5	NR	NR	NR	22.2
Relative Humidity (%)	62	NR	NR	NR	63

Trial Averaged 2-Meter Mast Data

	Sampler Line Position				
Parameter	001	026	076	101	
Averaged Wind speed (m/sec)	3.69	3.65	3.65	4.07	
Averaged Wind Direction (degrees)		195	205	206	205

Supplemental Meteorological Data

Solar Azimuth (degrees)	241.4
Solar Altitude (degrees)	61.0
Air Density (g/cu m)	1160.43
Barometric Pressure (milibars)	1012.87
Cloud Coverage (percent)	80
Psychrometric Relative Humidity (%)	56
Visibility (km)	108
Pasquill Category	C[a]
Bulk Richardson Number	M[b]
Wind Profile Exponent, 2-16 m	0.11
Solar Radiation (average Langley/min)	.51

a. M = Missing
b. NR = Not Required

TABLE 8. SUMMARY OF RELEVANT INSTRUMENTS LOCATED IN THE INSTRUMENTATION CLUSTER, SMOKE WEEK III....From Nelson and Farmer, 1981[2]

Cluster Instrument	Identification	Operating Agency	Measured Variable	Range of Measured Variable	Range of Uncertainty of Measured Variables (% of Measured Value)
Particle Sizing Instruments					
Electric Aerosol Analyzer	EAA	Univ. of TN S. I.	Size Distribution/ Number Density	0.005 - 1 µm $2 \cdot 10^3 - 5 \cdot 10^7$ @0.0µm $5 \cdot 10^5$@ 0.1 µ	±50% Over Size Range Greater than 0.024 µm
Electric Cascade Impactor	ECI	Univ. of Texas	Size Distribution/ Number Density	0.25 - 20µm $10^{-3} - 10^{12}$ cc^{-1} (10^5 Range/Instrument Setting)	±5 - 20%
Climet Particle Size Analyzer	PSA	Dugway P.G.	Size Distribution/ Number Density	0.3 - 10 µm $8 \cdot 10^2 - 10^5$ cc^{-1} (with dilution)	±10 - 100% Depending on Specific Size
Particle Sizing Interferometer	PSI	Univ. of TN S. I.	Size Distribution/ Number Density	0.2 - 6 µm/1.25-20 µm $10 - 10^6$ cc^{-1}	±30% @ 0.6 µm ±1% @ 6.0 µm
Particle Measurement Systems Particle Size Analyzer	PMS	Atm. Sc. Lab.	Size Distribution/ Number Density Range	0.15 - 10 µm $10 - 10^5$ cc^{-1} $5 - 10^3$ km^{-1} 0 - 100%	±4 - 100% Depending on Specific Size Presently Undetermined
Concentration Measurement Instruments					
Quartz Crystal Mass Monitor	QCM	Univ. of TN S. I.	Concentration	$10^{-1} - 10^3$ mg/m^3	±1% @ 1000 mg/m^3 ±10% @ 1 mg/m^3
Aerosol Photometer	AP	Dugway P. G.	Concentration	1 mg → 10 gm/m^3	±2% In Sample Acquisition ±4% Collector Efficiency ±2% Chemical Assay (P, HC) ±5% Chemical Assay (fog oil, diesel, and PEG 200)
Chemical Impinger	CI	Dugway P. G.	Time Integral Concentration (Dosage)	1 mg → 10 gm/m^3	±2% In Sample Acquisition ±4% Collection Efficiency ±2% Chemical Assay (P, HC) ±5% Chemical Assay (fog oil, diesel, and PEG 200)
Mechanical Mass Sampler	MMS	Dugway P. G.	Time Integral Concentration	≥ 1 mg	±2%

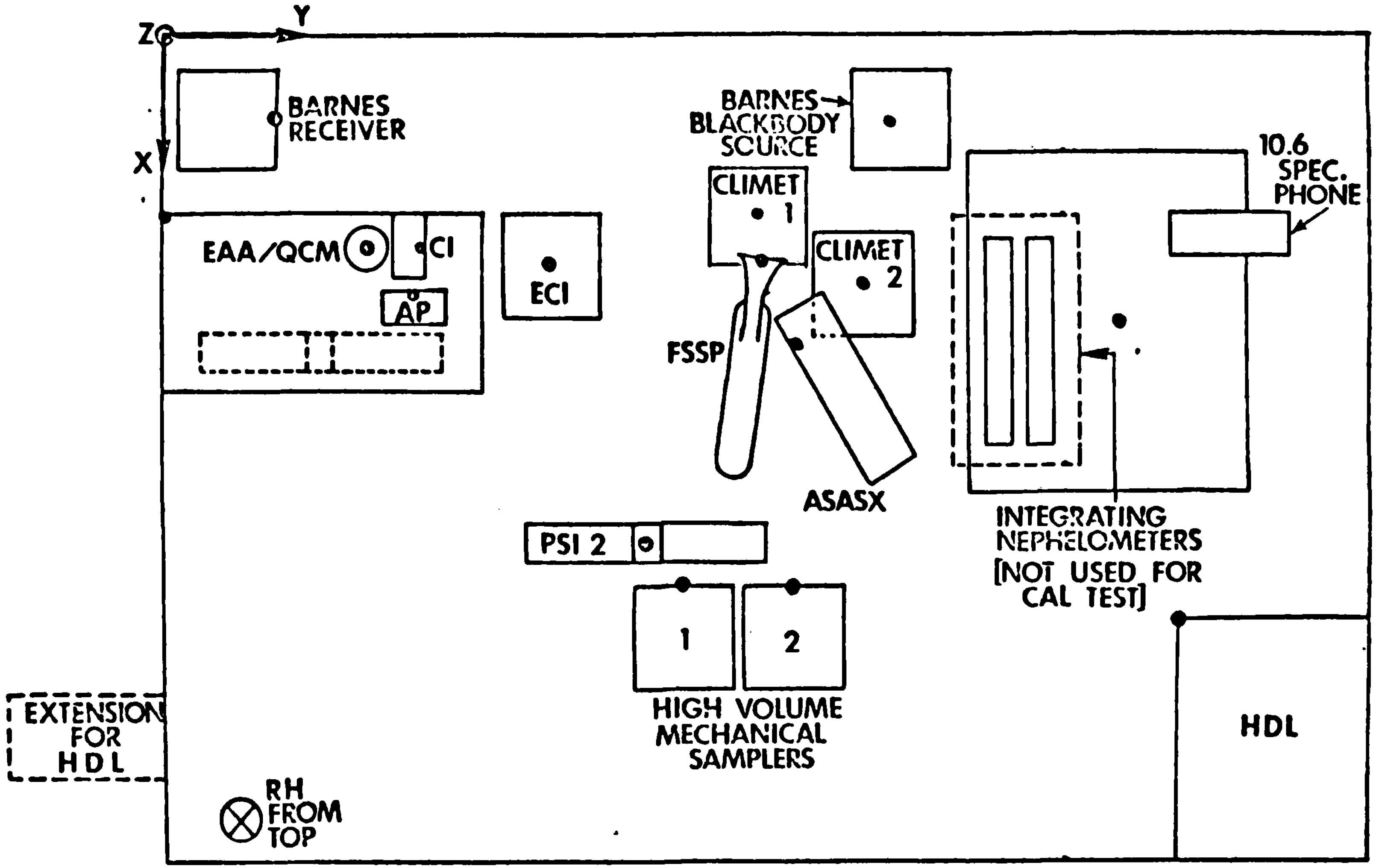


Figure 9. Instrument arrangement on test pad, Smoke Week III ....From Nelson and Farmer 1981.[2]

TABLE 9. POSITION SURVEY OF EQUIPMENT IN THE INSTRUMENTATION CLUSTER, SMOKE WEEK III....From Nelson and Farmer 1981[2]

Instrument	Y Position (m)	X Position (m)	Z Position (m)
1. Das Box	0	1.3208	-
2. Barnes Receive	0.8128	.6096	1.1303
3. EAA/QCM Inlet	1.5748	1.6002	1.4351
4. CI Center	1.9558	1.6256	1.4351
5. AP Inlet	1.905	1.8796	1.524
6. ECI	2.9464	1.7526	1.2446
7. PSI 2	3.6957	3.7211	1.016
8. High Volume Mechanical Sampler 1	3.9624	4.064	1.1112
9. High Volume Mechanical Sampler 1	4.7498	4.064	1.1112
10. Climet 1	4.5212	1.3462	1.0922
11. Climet 2	5.3086	1.8542	1.0922
12. Barnes Source	5.5372	.6504	1.143
13. FSSP-PMS	4.5212	1.778	1.3716
14. ASAS-X-PMS	4.699	2.286	1.3208
15. ASL Support Stand	7.239	2.136	-
16. HDL Nephelometer	7.6454	4.2926	1.7018[a]

a. to the center white light transmitter.

PARTICLE SIZING DATA--FOG OIL

A brief summary of particle sizing data is presented below. Table 10 presents particle size distribution measurements (using optical samplers) for Trials 2, 4, 8, and 19 for fog oil.

Several interesting conclusions may be derived from an analysis of the particle size data. Fog oil smokes were examined during Smoke Week III from the XM49 and the M3A3 smoke generators. Diesel oil smokes were produced by the VEESS vehicle exhaust system. The mass probability density distributions (i.e., the distribution of mass as a function of diameter) obtained from these systems are similar to those shown in Figure 10 which compare the mass distributions for the three systems using PSI 1 and PSI 2 measurements for trials 2, 4, and 14. Note in Figure 10 that the M3A3 and the VEESS generators put out larger mode sizes than the XM49. The multiple modes for the VEESS system shown in Figure 10 are due in part to a small population sample (less than 10^3 measurements) for the size measurements and some instability in the initial generator output (i.e., a mixture of smoke and oil droplets). The VEESS system was parked adjacent to the instrumentation cluster when these data were taken. The mass distribution obtained for the VEESS by PSI 1 located 30 m from the instrumentation cluster (Figure 10) shows fewer modes. The multiple modes and large number of small particles is consistent with the measurements obtained by using an electric cascade impactor (ECI) (Figure 11). Note that the ECI indicates particle diameters as large as 20 μm. No PSA data were obtained in trial 13. In Figure 10d, 2% of the mass was found to be in sizes greater than 6 μm while approximately 1% of the mass is contained in sizes less than 0.3 microns.

It is interesting to note how the size distribution for fog oil smoke evolves with time for a particular generator. In the initial stages of operation as in Figure 12a,b there is apparently a mixture of "large" oil droplets and "smoke". As the generator is adjusted, the oil droplets become a relatively insignificant component of the total smoke content. The stabilized output is a very dense smoke which is evidently produced with a relatively high oil utilization efficiency. The differences in the size distributions for an M3A3 generator start-up, adjustment, and stabilized output size distribution are in Figure 12a-c for trial 4. These data show that the size distributions represent a potential method for gauging generator efficiency. The data have revealed the the size distribution has spatial and time dependencies which presumably can be correlated through considerations involving atmospheric turbulence and wind velocity.

A summary of the moments of the measured size distribution in three fog oil trials of Smoke Week III is presented in Table 11. The causes for the sharp differences in measurements among instruments will be discussed in the next section.

TABLE 10. PARTICLE SIZE DISTRIBUTION (TRIAL AVERAGED PROPORTIONS/CHANNEL), BY PARTICLE SIZE RANGE, SMOKE WEEK III....From Nelson and Farmer, 1981[1]

Trial No.	0.3-0.4 µm	0.4-0.5 µm	0.5-0.6 µm	0.6-0.8 µm	0.8-1.0 µm	1.0-1.5 µm	1.5-2.0 µm	2.0-3.0 µm	3.0-4.0 µm	.0-5.0 µm
Fog Oil										
2	0.37	0.22	0.11	0.09	0.04	0.07	0.01	0.01	0.04	0.00
4	0.10	0.12	0.10	0.17	0.14	0.21	0.12	0.04	0.00	0.00
8	0.43	0.27	0.12	0.11	0.04	0.02	0.00	0.00	0.01	0.00
19	0.32	0.20	0.10	0.11	0.06	0.09	0.06	0.04	0.01	0.00

Note: The particle size distributions are presented in terms of number fraction.

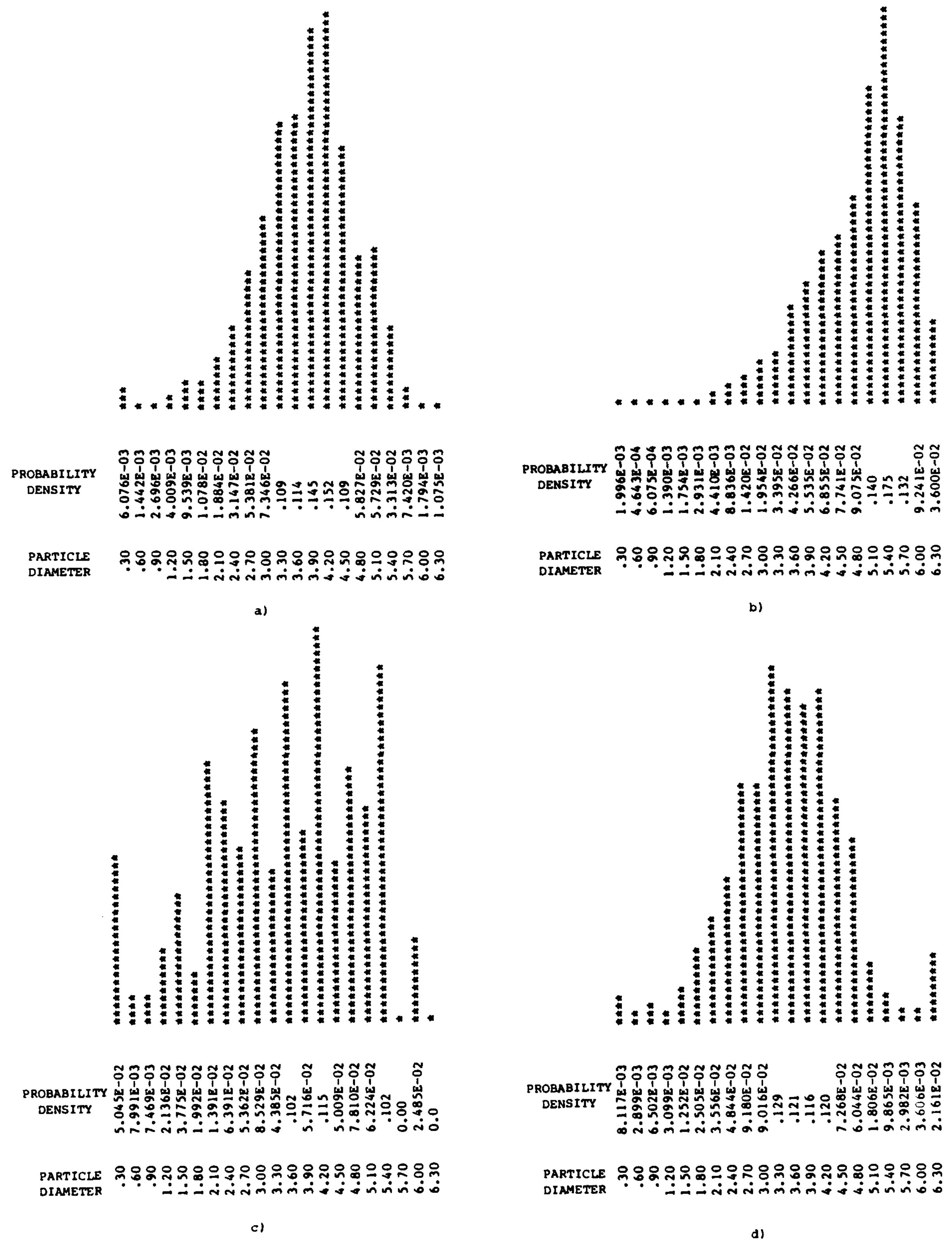


Figure 10. Comparison of ensemble averaged mass distribution for a) XM49 fog oil generator, b) M3A3 fog oil generator, c) VEESS diesel oil generator near the instrumentation cluster, and d) 30 m from VEESS oil generator...Smoke Week III....From Nelson and Farmer 1981.[2]

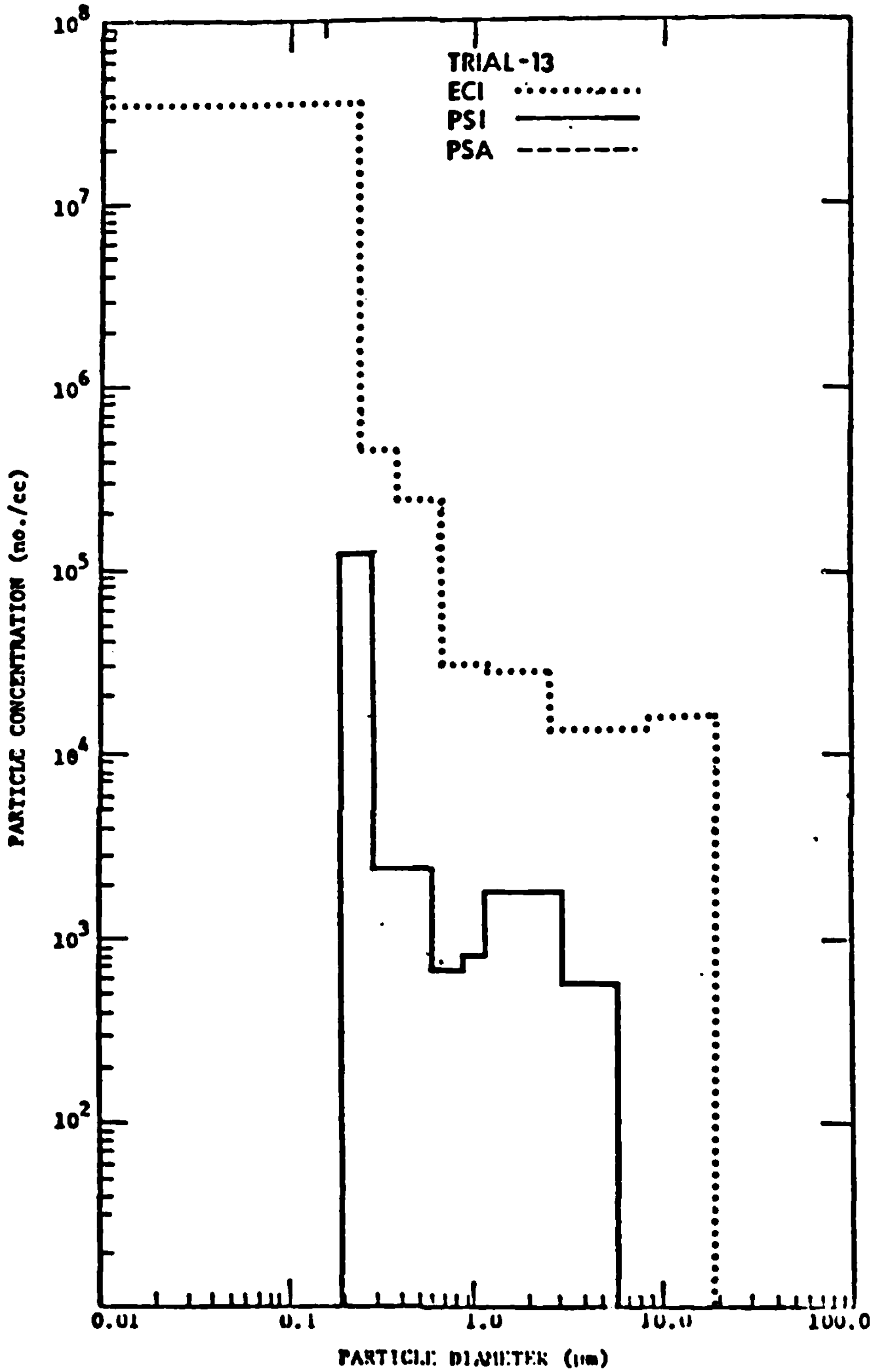


Figure 11. Comparisons of particle size distributions measured with the CI and PSI for trial 13 (VEESS with diesel oil), Smoke Week III ....From Nelson and Farmer 1981.[2]

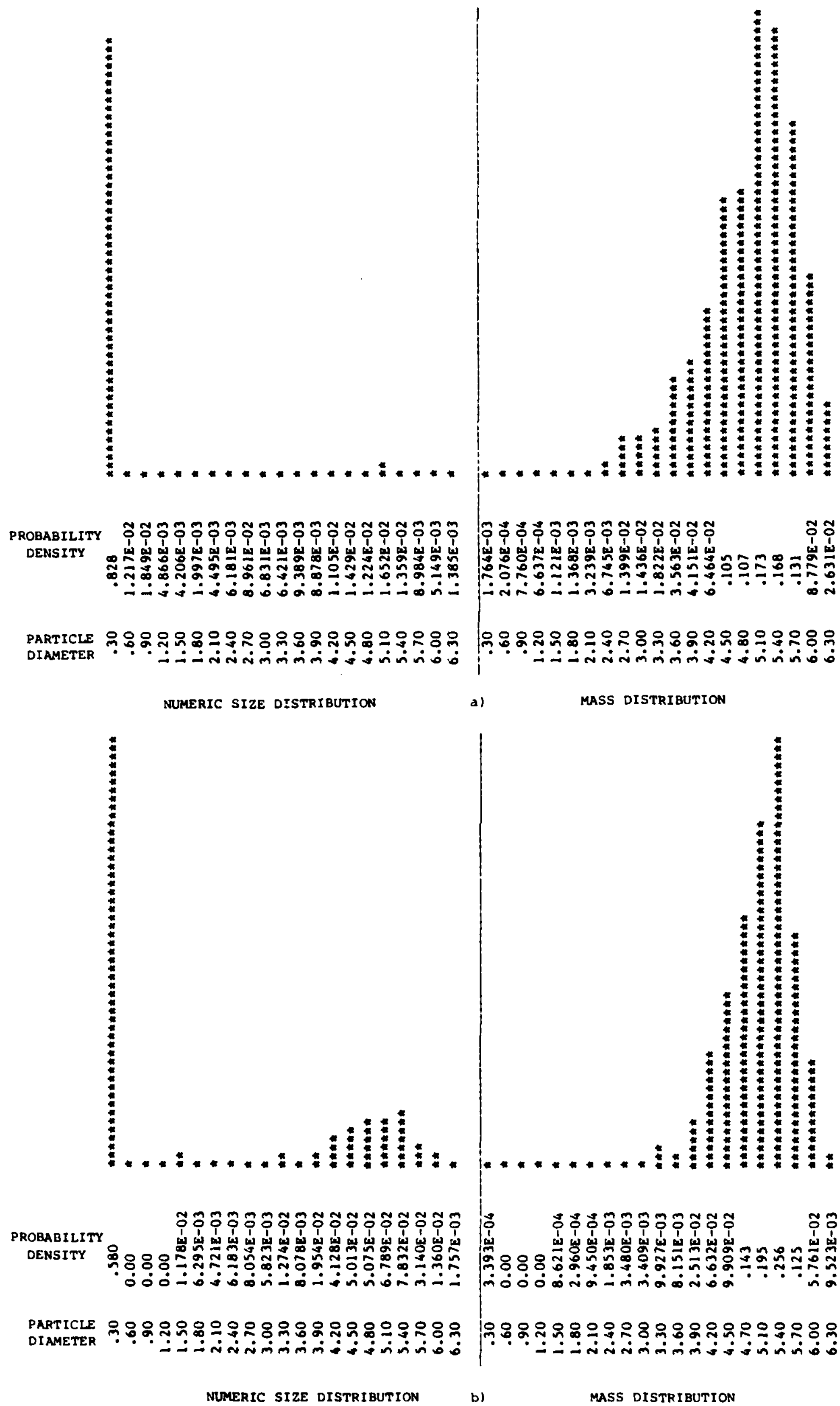


Figure 12. Evolution of size and mass distribution outputs from M3A3 fog oil generator. a) initial start-up, b) system adjustment...Smoke Week III....From Nelson and Farmer 1981.[2]

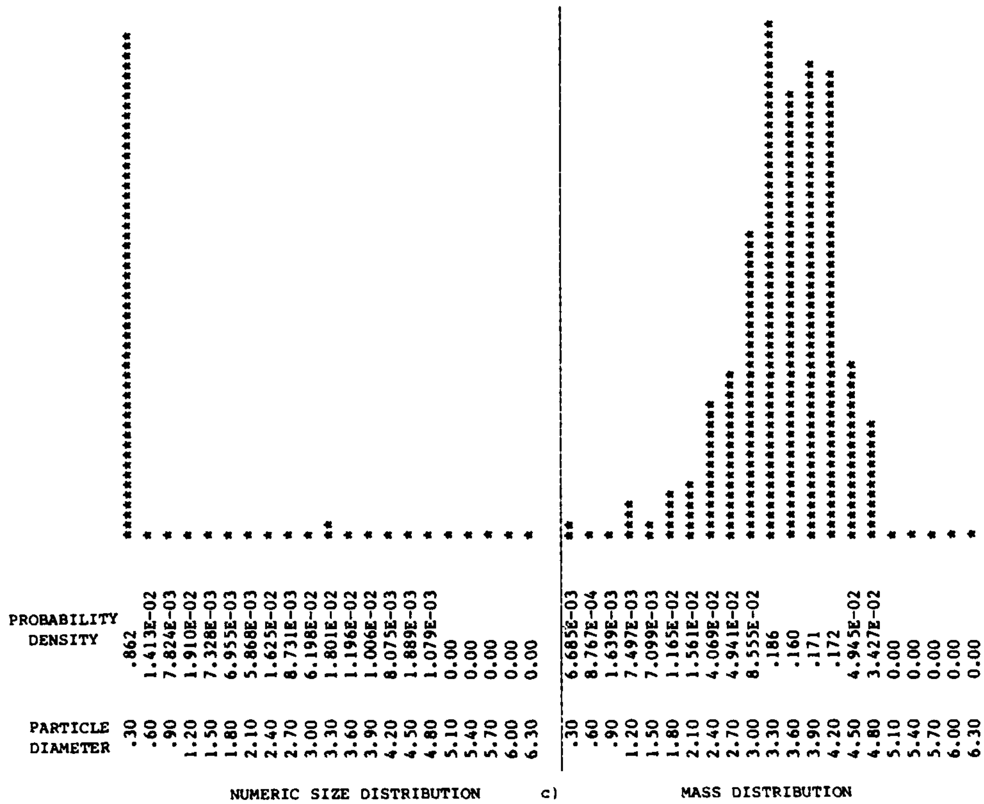


Figure 12c. Evolution of size and mass distribution outputs from M3A3 fog oil generator approaching stabilized output ....From Nelson and Farmer 1981.[2]

TABLE 11. SUMMARY OF MOMENTS OF THE MEASURED SIZE DISTRIBUTIONS: FOG OILS....SMOKE WEEK III....From Nelson and Farmer, 1981[2]

Trial No.	Obscurant	Relative Humidity (%)	Start Time	End Time	Instrumentation PSI 1	PSI 2	PSA	ECI[b]	PMS[a]
First Moments									
	Fog Oil (XM49)								
2.1		57	17:09:08	17:09:38	-	-	1.39	-	-
2.2			17:11:54	17:12:24	.511	-	1.17	-	-
	Fog Oil (M3A3)								
4.1		61	20:36:14	20:36:44	-	-	.828	-	-
4.2			20:37:28	20:37:58	.505	-	1.16	-	-
4.3			20:38:21	20:38:51	-	2.10	.945	-	-
4.4			20:39:22	20:39:52	-	1.04	1.17	-	-
	Fog Oil (XM49)								
19.1		80	21:46:20	21:46:50	-	-	1.50	-	-
19.2			21:47:32	21:48:02	.993	.348	1.21	-	-
19.3			21:54:07	21:54:37	-	-	1.02	-	-
Second Moments									
2.1		57	17:09:08	17:09:38	-	-	3.90	-	-
2.2			11:54:00	12:24:00	.779	-	3.25	-	-
	Fog Oil (M3A3)								
4.1		61	20:36:14	20:36:44	-	-	.940	-	-
4.2			20:37:28	20:37:58	.761	-	1.80	-	-
4.3			20:38:21	20:38:51	-	9.34	1.22	-	-
4.4			20:39:22	20:39:52	-	3.76	1.85	-	-
	Fog Oil (XM49)								
19.1		80	21:46:20	21:46:50	-	-	8.69	-	-
19.2			21:47:32	21:48:02	3.87	.228	2.16	-	-
19.3			21:54:07	21:54:37	-	-	1.43	-	-
Third Moments									
	Fog Oil (XM49)								
2.1		57	17:09:08	17:09:38	-	-	17.2	-	-
2.2			17:11:54	17:12:24	2.51	-	15.1	-	-
	Fog Oil (M3A3)								
4.1		61	20:36:14	20:36:44	-	-	1.49	-	-
4.2			20:37:28	20:37:58	2.43	-	3.54	-	-
4.3			20:38:21	20:38:51	-	46.1	2.24	-	-
4.4			20:39:22	20:39:52	-	18.3	3.80	-	-
	Fog Oil (XM49)								
19.1		80	21:46:20	21:46:50	-	-	72.7	-	-
19.2			21:47:32	21:48:02	21.3	.518	5.15	-	-
19.3			21:54:07	21:54:37	-	-	2.63	-	-

a. Steady State Calculations
b. Aerodynamic Calculations

PLUME PHYSICAL PARAMETERS--FOG OIL

On a number of occasions in Smoke Weeks III and V, the MIDAS system[3] was used to provide a video picture of the moving plume. Obscurant cloud dimensions were obtained in six simultaneous wavelength sets from the 0.5-0.7 μm band to the 8-14 μm band. Video images were obtained from each of two camera stations placed in the near-field area of the plume. For each two-dimensional scene, an ellipse was fitted to the cloud perimeter. The geometric projection of time-coincident pairs of these ellipses (one from each camera) into a common three-dimensional object-space coordinate system allowed ASL to calculate the ellipsoid parameters that describe the solid form of the cloud, the associated plume dynamics and the position of the plume with time. Plume data obtained from the data reduction process were:

Horizontal Extent - The width of the ellipsoid cross-section (normal to LOS) at the two most widely spaced lateral points of the perimeter.

Vertical Extent - The distance between the greatest vertical separation of points on the perimeter of the ellipsoid cross-section (normal to LOS).

Area - Square measure within the ellipsoid cross-section perimeter.

Lateral Offset - Distance measured in the horizontal plane of the track of the ellipsoid centroid.

Path Length - The vector segment distance of the optical path (LOS) from the entry to exit points on the ellipsoid surface.

Volume - Cubic measure of the ellipsoid.

Centroid Height - The vertical distance of the centroid from the horizontal plane that contains the detonation point. This measure provides the best estimate of the position of the center-of-mass.

Transport Direction - The geographic azimuth of the ground track of the ellipsoid centroid.

Transport Rate - The elapsed time of movement between centroid points on the ground, in meters/second.

An example of the output of this process is given in Table 12 and Figures 13 and 14 for Smoke Week III, Trial 4. Table 12 provides a listing of the geometry information (the items listed in the preceding paragraph). Figure 13 provides the three-dimensional cross-sections of the temporal sequences of the ellipsoids. The envelope of these sequences would represent the extent of plume spreading during the first 20 seconds after generator start up. Figure 14 provides a graphic that summarizes trends of the key measurements as a function of time. It should be noted that the MIDAS system operated only in the near field of the plume and the main objective was to characterize plume dimensions through the lines of sight set up for the trial. The horizontal dimensions of the cloud were found to be accurate to approximately ±10% based on a comparison study with helicopter photographs made in Smoke Week V. In that study, the horizontal dimensions of the plume clouds from various tests in Smoke Week V were intercompared using (a) values obtained with the MIDAS

TABLE 12. LISTING OF GEOMETRY INFORMATION FOR PLUME CLOUD, SMOKE WEEK III, TRIAL 4....From Blackman 1982[3]

SMOKE III EGLIN AFB, FLA

EVENT 04 TIME 2033Z DATE 081180

A3M3 FOG OIL SENSOR 0 5-0 7

TIME (SEC)	DIMENSIONS OF OBJECT CROSSECTION NORMAL TO OPTICAL PATH (METERS) HEIGHT (REF DET PT)	HORIZONTAL EXTENT	VERTICAL EXTENT	AREA (SQ. METERS)	LATERAL OFFSET	PATH LENGTH	DIMENSIONS INDEPENDENT OF PERSPECTIVE VOLUME (CUBIC METERS)	CENTROID HEIGHT	TRANSPORT DIRECTION	TRANSPORT RATE
0.0	2.3	2.7	2.6	5.5	2.2	0.0	22.3	1.0	0.0	0.0
1.0	2.9	3.4	3.3	9.0	1.1	0.0	41.1	1.2	27.0	1.1
2.0	3.4	4.8	4.1	15.3	0.0	0.0	71.8	1.3	27.3	1.2
3.0	3.8	6.4	4.7	23.6	-1.3	0.0	112.9	1.5	27.6	1.2
4.0	4.3	8.2	5.3	34.2	-2.5	0.0	168.2	1.6	27.8	1.3
5.0	4.7	10.1	5.9	46.5	-3.8	0.0	236.3	1.8	28.1	1.4
6.0	5.1	12.2	6.4	61.1	-5.2	0.0	322.1	1.9	28.3	1.4
7.0	5.4	14.4	6.8	77.5	-6.6	0.0	424.8	2.0	28.5	1.5
8.0	5.8	16.7	7.3	96.4	-8.1	0.0	551.2	2.1	28.7	1.5
9.0	6.1	19.1	7.8	116.8	-9.6	0.0	692.3	2.2	28.9	1.6
10.0	6.4	21.5	8.2	138.8	-11.2	0.0	852.9	2.3	29.0	1.6
11.0	6.8	24.1	8.7	163.3	-12.9	0.0	1040.8	2.4	29.2	1.7
12.0	7.0	26.7	9.1	189.2	-14.6	0.0	1244.4	2.5	29.3	1.7
13.0	7.3	29.4	9.5	216.7	-16.3	3.1	1468.3	2.6	29.5	1.8
14.0	7.6	32.1	9.8	245.5	-18.1	6.7	1707.0	2.7	29.6	1.9
15.0	7.8	34.9	10.2	276.1	-20.0	8.5	1972.1	2.7	29.7	1.9
16.0	8.1	37.8	10.6	308.8	-21.9	9.7	2262.1	2.8	29.8	2.0
17.0	8.3	40.8	10.9	341.5	-23.8	10.5	2550.0	2.9	29.9	2.0
18.0	8.6	43.8	11.3	377.0	-25.8	11.1	2880.0	2.9	30.0	2.1
19.0	8.8	46.9	11.6	412.4	-27.9	11.4	3202.0	3.0	30.1	2.1
20.0	9.0	50.1	12.0	449.8	-30.0	11.7	3556.2	3.0	30.2	2.2
21.0	9.2	53.3	12.3	487.8	-32.2	11.9	3914.0	3.0	30.3	2.3
22.0	9.4	56.6	12.7	526.1	-34.4	12.0	4274.6	3.0	30.4	2.3

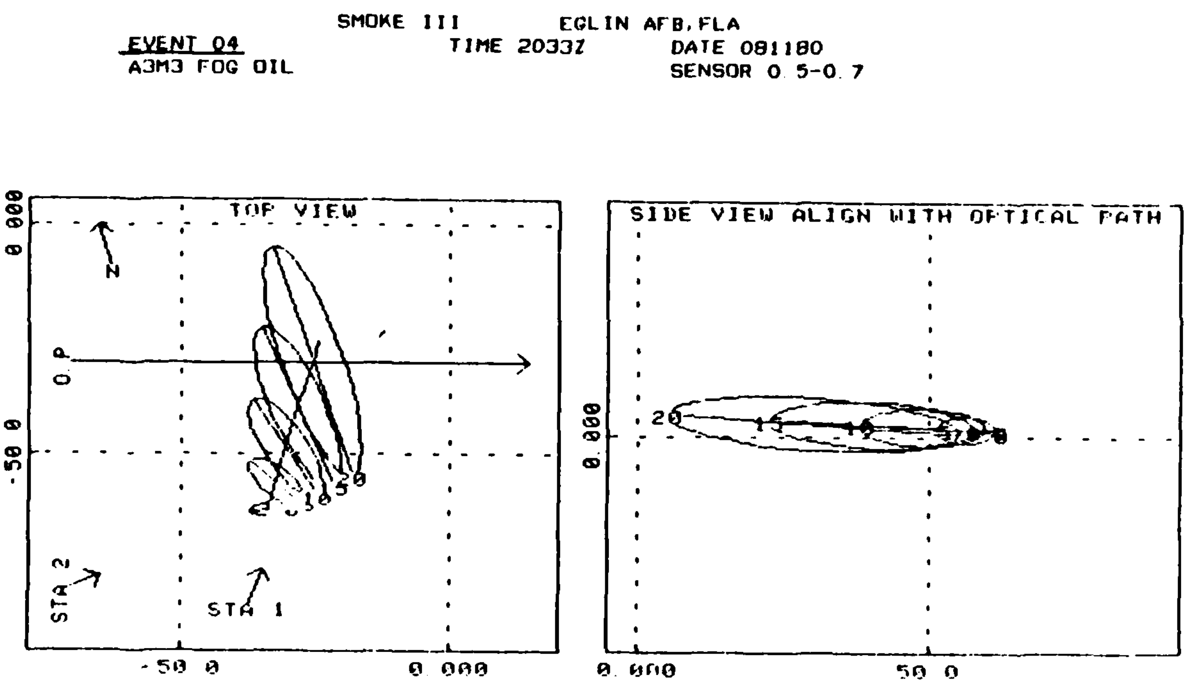


Figure 13. Three-dimensional cross sections of the temporal sequences of the ellipsoids...Smoke Week III, Trial 4....From Blackman 1982.[3]

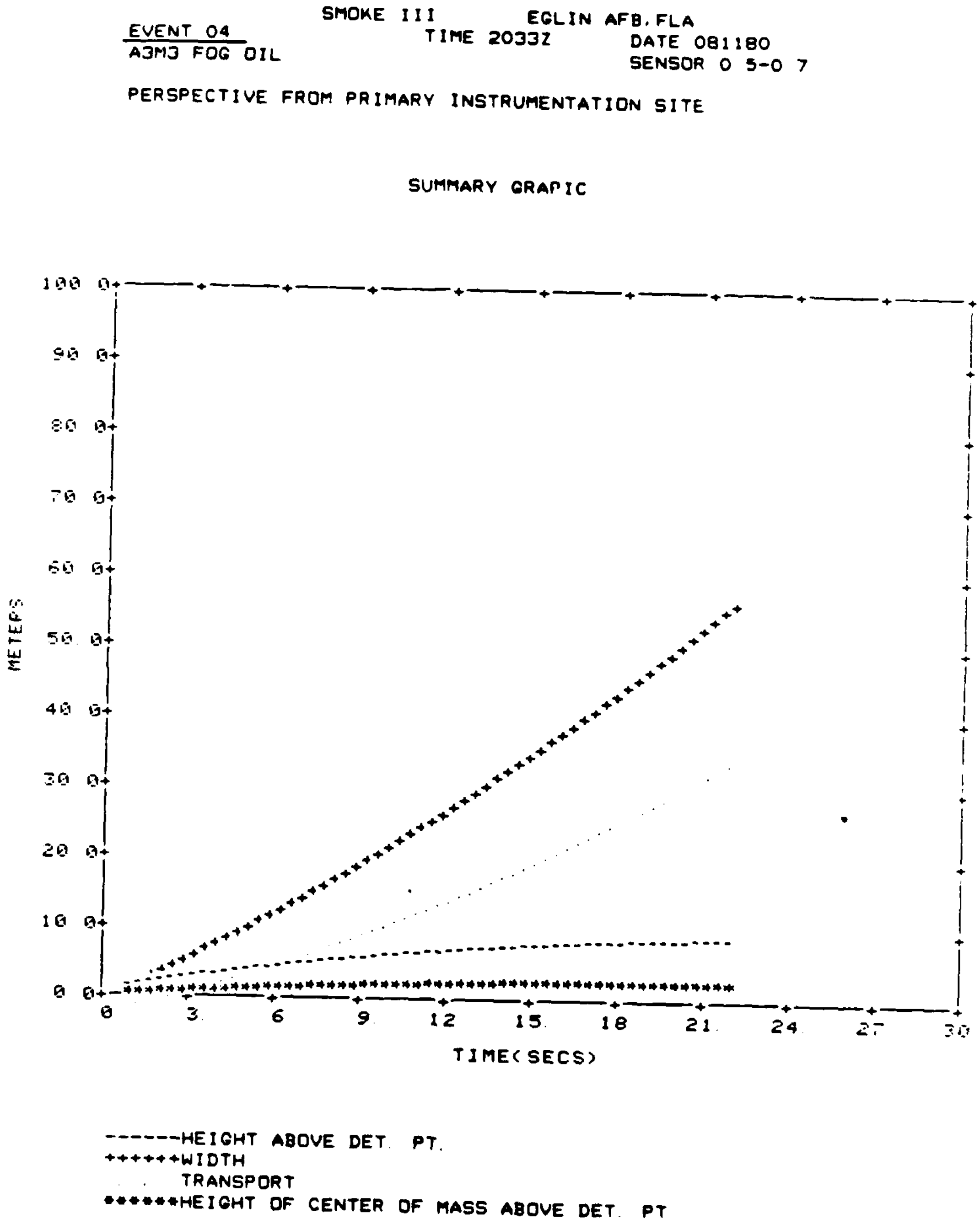


Figure 14. Summary of trends in the key measurements obtained form the MIDAS System...Smoke Week III, Trial 4 ....From Blackman 1982.[3]

system, and (b) cloud dimensions obtained from analzying helicopter photographs of the same dispersing plumes. MIDAS data are available for most tests in Smoke Week III.

DISCUSSION OF THE QUALITY OF THE EXISTING DATA

The quality of the Smoke Week data for model evaluation purposes is largely unknown, and questionable at best. Important questions have been raised concerning the sampling methods and supporting meteorological and source release data. These questions remain unanswered largely because no one has evaluated the internal consistency of the data base or has tested models with the data. Little quality assurance was done in the field and no estimates were attempted of the error inherent in each measurement point. Trials were repeated from one Smoke Week to another without a detailed analysis of the results of the previous Smoke Week's data. Only recently have these data begun to be placed in a data base (at Science and Technology, Inc. in Las Cruces, New Mexico) and made available to potential users. Smoke Symposia contain papers of model developers testing their models with selected Smoke Week data. Unfortunately, the data chosen for testing were very limited in quantity and model/data comparisons were largely model fitting exercises. No extensive model testing has been done and no analysis of the meaningfulness and consistency of the data has been attempted.

At Science and Technology, Inc., data from Smoke Weeks II, III, and IV have recently been entered into the data base. At this writing, Smoke Week V data are being entered. Smoke Week VI was not yet ready for publication in the Smoke Week report series. This effort to collect all the data and keep it in a usable format has been long overdue. It was only at Smoke Week III that the better quality data were taken. Since our interest is largely in concentration measurements, this limits our interest to data from Smoke Weeks III and IV. Placement of long rows of aerosol photometers ceased with Smoke Week IV. Limited data on concentrations with time and particle size distributions are available in later Smoke Weeks; however, those data are too sparse for effective utilization in a model validation program.

At this point, the uncertainties that surround these collected data will be discussed in order to provide a proper perspective on the quality of the data that are available.

METEOROLOGICAL DATA

The meteorological data taken in Smoke Weeks III and IV were acquired by Dugway Proving Ground. Table 13 provides their specification of accuracy of their meteorological instruments in the field. A summary of some of the problems with the Smoke Week IV data follows.

First, the temperature and temperature/dew point systems used on the meteorological tower translated sensor response into millivolts. Because of the small voltages involved, these systems were sensitive to electronic noise interference. The aspirator motors, electric pumps, power cables, and other signal-generating devices provided a noise background which was superimposed

TABLE 13. ACCURACY OF SMOKE WEEK IV METEOROLOGICAL DATA ACCORDING TO DPG....From Burgess and Nielsen 1982[4]

Measurement	Accuracy
Wind Speed[a]	±1 percent or 0.15 m/sec, whichever is greater; threshold is 0.27 m/sec and distance constant = 1.5 m
Wind Direction[a] (Horizontal and Vertical)	±3 degrees; threshold is 0.34 m/sec and distance constant = 1.0 m
Temperature, Dew Point (at 2- and 32-m levels)	±0.5°C
Temperature (at 0.5- and 4-m levels)	±0.5°C
Temperature Differentials (at 0.5- and 4-m levels)	±0.5°C
Solar Radiation	±1 percent; wavelength band 0.32-2.5 μm, response time = 4 sec

a. Performance data are from the manufacturer. Actual field performance may be different and require independent evaluation.

onto the data signal. The problem was further complicated by grounding faults and noise originating somewhere in the pulse coded modulation (PCM) system located in a van. Attempts at noise suppression (using capacitors) were only partly successful. The noise signals appeared to be random in nature. As a result, the temperature, temperature difference and dew point data are inaccurate. As stated in Reference 1:

"Due to noise and siting problems, the Climet CI-60 temperature data should be interpreted as approximations for trial-averaged values only. System accuracy is insufficient for temperature profile (ΔT) determinations. The noise component is sufficiently large to compromise any attempt at finer temporal resolution of these data."

Consequently, the ΔT data should be ignored. Determination of stability need be done from indirect means such as using data on cloud cover, cloud height, and solar radiation. From that determination, a very rough approximation of dT/dZ can be determined for model input.

Second, the 16-m wind speed readings are low, probably due to bearing drag in the anemometer.[2] The 16-m speeds were recalculated for the "Summary of Test Day Data." These adjusted wind speeds were also used in the 2 to 16-m wind speed profile exponent computations.

A more serious problem involved the location of the mobile measurement unit too close to the meteorological tower in Smoke Week IV. Effects of the MMU are evident in all trials (wind direction 270-340°). As a result, the wind speeds, wind directions, and horizontal standard deviations below the 10 m level, and the 2 to 16-m wind velocity profile exponents are not representative of ambient conditions for those wind directions.

A third serious problem involved the site itself as not ideal for these types of measurements. The combination of elevated roadways and other obstacles to free airflow at the TA-1 site in Smoke Week IV caused significant variations in roughness for the tower-mounted meteorological instruments as wind direction changed. To support atmospheric dispersion measurements, the meteorological tower should be located at a site with roughness comparable to the roughness of the site over which the dispersing cloud travels. Because of the complexity of the roughness problem, no roughness estimates were provided.

Finally, the lack of micrometeorological measurements led to a loss of information involving the ambient turbulence and boundary-layer dynamics. Such information is most useful to interpret the physical state of the ambient atmosphere during a test and is helpful in evaluating the Monte Carlo models. Such data are also very helpful during model development.

In summary, the presence of the MMU as an obstacle in front of the meteorological tower, the poor ΔT measurements, and the non-flat terrain leading to some complex meteorology led to difficult problems in the interpretation and utility of these meteorological data in Smoke Week IV. Similar problems occurred in Smoke Week III except for the MMU interference.

SAMPLER DATA

Dosage values determined from the aerosol collected in chemical impingers and filter samplers are dependent on sampler flow rate, collection efficiency, and the chemical analysis of the sampler contents. The most serious problem with the sampler data revolves around the chemical impinger measurements. DPG analysis of the AP and CI data for the rows of samplers in Smoke Weeks III and IV revealed the following:

(i) the AP data when integrated in time to provide dosages revealed a normal-type distribution as expected with a peak near the centerline of the plume. Except for ±20% variations, the Gaussian shape was intact.

(ii) Unfortunately, the dosages from the corresponding CIs were not Gaussian. For instance, centerline values were not the peak values; the actual distribution of CI measured dosages had no resemblance to a Gaussian profile.

(iii) Since the APs provide only a relative measure of concentration, each needs to be properly scaled to give the true concentration. The purpose of the CIs (one CI for each AP) was to provide the appropriate scaling through a comparison of CI-measured dosage and the integrated concentration versus time from the AP. Once this ability to scale the AP measurements was lost, the value of the apparently correct profile shape of the APs was placed in doubt.

(iv) The decision at DPG was made to subjectively determine a single scaling factor to be applied to all APs. The original plan was to have a separate scaling factor for each AP based on the measured dosage from its companion CI. Choice of a single scaling factor would thereby maintain the Gaussian shape observed from the APs, but its choice would be difficult due to apparent inconsistency in the lateral profile of concentration dosages obtained from the CIs. The scaling factor was chosen after throwing out those data that looked incorrect.

Nielsen[9] suspects that the problem lies in DPG laboratory procedures in reducing the CI data. The problem has resisted solution for many years and has been present whenever the CIs have been used in the past at Dugway. It is present not only for fog oil smokes, but all smokes for which the CIs have been used.

Farmer[8] believes that the CI data problem is due to a collection efficiency problem. The chemical impingers used by DPG are usually oriented normal to the wind during placement. Farmer noted that for most efficient collection they should be oriented directly towards the wind. Placing them on some sort of wind vane would improve collection. Also, the inherent problem of isokinetic sampling of a turbulent wind field may be a related cause. Sampling errors depend on the aspirated flow rate, the wind speed, direction, and turbulence level and shape of orifice used for the sampling. Indeed, the collection efficiency is difficult to estimate.

The isokinetic sampling problem affects the aerosol photometers to a greater degree. Farmer[8] estimates an error of a factor of 2 using such an instrument. In addition, critics have asserted that the response time of the AP is too slow to resolve the peaks in concentration measurements. Since we are predominantely interested in dosages, however, the former question is of greater concern.

Problems with the mobile measurement unit occurred as well. In Smoke Week III, local physical obstructions (presence of barrels) affected the turbulence field which influenced the measurements. Realizing this problem, an instrument pad was constructed for Smoke Week IV and placed upwind in such a way that no instrument was in the wake of any other or any obstruction.

The quality of the data from the particle size analyser (PSA) has also been questionable. In Smoke Week IV, the PSA was positioned under the floor of the MMU with the probe attached to a sampler probe common to the University of Tennessee Space Institute (UTSI) samplers through a series of tubing approximately 1.8 m long. The quality of the PSA data has therefore been questioned on the following bases.[5]

(1) Lengths and bends of tubing to the PSA may have modified sampling,

(2) Questionable isokinetic sampling. The nozzle appeared to be a fixed-flow nozzle; therefore, entrance or inlet pressure matches atmospheric pressure at only one wind condition or at best at very discrete wind conditions (considering wind direction and speed), and

(3) The transition interface did not provide for laminar flow and may have caused selective extraction of particles.

Also, the glass fiber filters used for sampling single and dual obscurants were not characterized for collection efficiency because of lack of time and unavailability of material and personnel. Data from preliminary wind tunnel calibration of the glass fiber filter sampler indicate that the dosage may be too large by 30 percent or greater depending on wind speed, orientation of the sampler, and other factors. Therefore, caution should be used when using Smoke Week IV dosage data from the filter samplers.

SOURCE DATA

Available are the locations of the munition and the exact times of its startup and shutdown. Unfortunately for fog oil smokes, the smoke generator takes approximately 5-10 minutes to reach thermal equilibrium. Unfortunately, this startup period was the time period used in all the fog/oil trials. An unsteady source complicates the problem since mass as a function of time was also measured in these experiments. Only total mass of fog oil expended was recorded. One is, therefore, forced to make the assumption of constant mass release rate with time. Also, no exhaust droplet size distribution was taken. Stack sampling devices can be used to provide such a measurement and should be used in future experiments. The determination of whether the generator runs "wet" or "dry" depends on the mode of operation employed by the generator operator. The mode of operation will affect the droplet sizes that are released to the atmosphere.

The exhaust temperature of the generator is also not measured in fog oil tests. This temperature is useful because it allows the estimation of the initial plume buoyancy simulated in the models and it also determines which fog oil constituents enter the vapor and aerosol phases.

As mentioned earlier, the data were acquired not for the purpose of model validation but to allow government developers and managers of electro-optical (EO) systems and others to evaluate their work and hardware under simulated field conditions. A field program aimed specifically at evaluating plume transport models would be designed differently.

MATHEMATICAL MODELS SELECTED FOR EVALUATION

In addition to surveying the available data in the literature, another objective of this survey report is to identify which models are appropriate candidates for evaluation for the purpose of predicting the environmental and health effects of smokes. Twelve candidate models have been identified as a result of a review of their theoretical formulations and previous applications. A brief description of each model is presented in Table 14. Eight of the 12 models were developed for the U.S. Army specifically to handle smoke/obscurants problems and fog oil plumes as a special case. Four models developed outside the U.S. Army community were added to the list for evaluation because they show special promise for fog-oil dispersion calculations. These four models (INPUFF, RIMPUFF, Ludwig (1977), and

TABLE 14. MATHEMATICAL MODELS IDENTIFIED FOR EVALUATION WITH FIELD DATA IN THE PRESENT STUDY

1. HECSMOKE-I[10]--R. Cheney and K. Dumbauld; Harry E. Cramer, Inc.; Salt Lake City, Utah

   This is a Guassian model developed largely from data taken at Dugway Proving Ground. The model has a user's manual and predicts concentrations with time and total dosages.

2. HAZRD2[11-13]--R. Pennsyle and R. Winkler; CRDC; Aberdeen Proving Ground, Maryland

   HAZRD2 is a Gaussian model which predicts concentrations and deposition rates. It is an improved version of the D2 model.[12]

3. ACTMAD[14]--B. Matise et al.; Optimetrics, Inc.; Ann Arbor, Michigan

   ACTMAD is actually two codes in one. If run in its ACT II mode, ACTMAD is identical to the standard ACT II model developed by ASL. ACT II simulates obscurant smoke plumes using a standard Gaussian puff technique. If run in its MAD Puff mode, it uses the MAD Puff turbulent transport methodology with a choice of three buoyancy models available. In MAD Puff, puff locations are randomized at each time step based on atmospheric turbulence data. The ACTMAD model predicts concentrations but not deposition rates.

4. MoCaPD[15,16]--K.H. Huang and W. Frost; FWG Associates, Inc.; Tullahoma, Tennessee.

   This Monte Carlo particle dispersion model predicts concentrations, but not deposition rates from continuous and burst releases. The model has the capability of predicting the particle-size distribution and particle number density at any location and time.

5. Ohmstede-Stenmark Model[17]--Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico

   This Monte Carlo model predicts trajectories of particles released from continuous or burst munitions. In its present form, the model does not predict ground-level concentrations or deposition rates, but rather may be used for plume "visualization" or to compute moments of the vertical distribution of concentrations.

6. COMBIC[18]--D. Hoock, R. Sutherland, H. Maynard, and R. Thomas; Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico

   The COMBIC model predicts cloud histories from a number of obscurant sources which may be selected from a menu or be user specified. The model treats buoyant rise and dispersion using the theories of Briggs and Morton, Taylor, and Turner. The model treats fog-oil releases as a continuous plume rather than by means of a puff methodology.

TABLE 14. (CONTINUED)

7. MSMOKE[19]--P. Hansen; Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico

   MSMOKE is a Gaussian model which can handle the dispersion from single and multiple fog-oil smoke generators. The model is written in BASIC and runs on the HP9845 and Apple II computers.

8. Ludwig (1977)[20]--F. Ludwig; Stanford Research Institute; Palo Alto, California

   The Ludwig (1977) model is a simple Gaussian puff model which can treat plume dispersion with time-dependent meteorology. The model runs on a microcomputer.

9. INPUFF[21,22]--W. Petersen; U.S Environmental Protection Agency; Research Triangle Park, North Carolina

   This model is a Gaussian puff model which treats time-dependent meteorology and emission rates. The model provides the user with a choice of two dispersion schemes: the Pasquill scheme and a scheme which employs on-site turbulence data. This model is commonly used in the chemical industry to simulate the dispersion of toxic vapor releases.

10. RIMPUFF[23,24]--T. Mikkelsen, S. Larsen, and S. Thykier-Nielsen; Risø National Laboratory; Roskilde, Denmark

   This is a puff diffusion model which treats time-dependent meteorology and emission rates. The model simulates the shearing of puffs in the vertical direction which can be important in stable conditions. The model has been validated with field data on smoke dispersion using the BOREX field experiments in Denmark. The model has been developed ·r the last eight years and is currently being expanded to handle complex terrain. The model predicts concentrations as a function of time as well as dosages.

12. Boughton-Dunn[25]--University of Illinois at Urbana, Illinois

   This Monte carlo model predicts concentrations and deposition rates from near-ground and elevated releases including the effects of settling and deposition. The model includes particle growth, evaporation and chemical transformations as well as a detailed treatment of the micrometeorology.

Boughton-Dunn) have unique theoretical features that make them worth a detailed investigation.

It should be recognized that the U.S. Army models (except perhaps for HECSMOKE-I and HAZRD2) were developed to predict concentration as a function of time and space for the purpose of evaluating the obscurant properties of the smoke cloud. Although the purpose of such models was to calculate concentration integrated along a line of sight, transmittance and/or plume intermittency, such smoke/obscuration models can be made to provide dosage by time-integrating the predicted concentration over the time of the smoke release. The performance of these obscuration models in predicting health effects and environmental impacts will be determined in the current study.

In determining the appropriate models for evaluation, those models were eliminated from consideration that provided either no unique features or were superceded by later versions. In addition, only two models (HAZRD2 and Boughton-Dunn) described in Table 14 predict deposition rates. Also, only the Monte-Carlo models (MoCaPD, Ohmstede-Stenmark, and Dunn-Boughton) can predict particle size distributions.

FUTURE PLANS FOR MODEL EVALUATION

The principal objectives of the model evaluation portion of the project are:

(a) to document the performance of the popular and promising predictive models using field data on dosages and deposition rates produced by smoke generators and munitions, and

(b) to develop improved models (as needed) based on the successes and failures of the existing models.

The Smoke Week data along with new field data acquired as part of the current project should provide an excellent basis for model evaluation and improvement.

As noted earlier, the field and analytical portion of the research project is currently focused on the dispersion of fog oil smoke plumes. Available data from the Smoke Weeks that may be used for model testing are:

- Smoke Week III, Trials 2, 4, 8, and 19
- Smoke Week IV, Trials 3, 6, and 38

Smoke Week III data will be used first since it contains two lines of samplers whereas the Smoke Week IV data contain only one row of samplers. To be noted are some additional limitations that exist with the Smoke Week IV data. For Trial 3, the particle size data are questionable.[5] For trial 6, no aerosol photometer data were taken; chemical impinger data were acquired at only six locations including the MMU. Also, the XM49 was moved several times during the trial to assure that the cloud was entering the instrument van. For Trial 38 of Smoke Week IV, the AP and CI data were taken (one horizontal row and one vertical row), yet the particle size data were also questionable

here as well. In this trial, two XM49 generators were co-located. After two minutes of generation, one XM49 was moved eastward to a point 5 m west of center.

Model/data comparisons will be made for:

(a) concentration dosages along the one (Smoke Week IV) or two (Smoke Week III) horizontal lines of sight at which lateral distributions were measured. Comparisons of the σ_y's will be made at each cross-section. Also, comparisons of the vertical distribution at the one tower location will also be made and σ_z's will be compared as well.

(b) concentration as a function of time, and

(c) particle size distribution for those models which are able to predict it (MoCaPD, Ohmstede-Stenmark, Dunn-Boughton Model).

Data will be used for model testing as they are available on a trial by trial basis. Some models will have difficulty handling two smoke generators (Smoke Week IV, Trial 38) or the movement of a smoke generator during a trial (Smoke Week IV, Trials 6 and 38). Models will be run as they apply to a particular trial.

Model performance for the prediction of dosages and, to a limited extent, particle size distribution, can be evaluated based on these Smoke Week data. Model evaluation at longer distances and for longer runs of the smoke generator will only be possible with the data acquired as part of the current project.

Once the model/data comparisons have been prepared, an analysis of the results will be made to determine the causes of the model/data discrepancies. This analysis will be aimed at tracing back the model/data discrepancies to physical assumptions in the model formulation. Among the questions of interest in the examination of these comparisons are:

(i) Is there any special advantage to either the quasi-steady state Gaussian, variable trajectory Gaussian puff, or Monte Carlo approaches in predicting the variables of interest to health and environmental effect researchers?

(ii) Do any of the competing methods of treating lateral and vertical dispersion appear to have advantages over the others?

(iii) Are there any special physical processes that are not included in the models that should be for accurate modeling? For example, does the treatment of shear during stable conditions provide an important physical mechanism that should be included in the models?

(iv) How sensitive are the models to their input conditions? Also, how sensitive are the models to the treatment (or lack of) of the initial buoyancy and momentum of the exit plume?

(v) Is there significant degradation in the performance of the models with distance from the source or under special meteorological conditions?

The use of standard statistical tests and graphical means of comparison will be used to evaluate model performance.

Once the results of the model/data comparisons have been fully analyzed, it is anticipated that a "generic" model will be developed to identify the best combination of physically reasonable assumptions. The resulting improved model will then be made available for environmental impact evaluations. Future reports in this series will present new field data and modeling results.

REFERENCES

1. Grose, E. C., M. J. K. Selgrade, K. Dean, G. E. Hatch, J. W. Illing, A. G. Stead, F. J. Miller, D. W. Davies, M. J. Wiester, J. A. Graham, R. J. Jaskot, M. A. Stevens, J. S. Tepper, and J. Hardesty, 1985, "Pulmonary and Systemic Health Effects of Acute and Subchronic Exposure to Smoke Obscurant SGF-2," Proceedings Smoke/Obscurants Symposium IX, 23-25 April 1985, Adelphi Maryland, Report Number AMCPM-SMK-T-002-85, sponsored by PM Smoke/Obscurants.

2. Nelson, J.G. and W.M. Farmer, 1981, "Electro-optical Systems Performance and Characterized Obscured Environments at Eglin Air Force Base, Florida," U.S. Army Project Manager for Smoke/Obscurants, DRCPM-SMK-004-81, Aberdeen Proving Ground, Maryland.

3. Blackman, G.R, 1982, "Cloud Geometry Analysis of the Smoke Week III Obscuration Trials," U.S. Army Electronics Research and Development Command, Atmospheric Sciences Laboratory Report ASL-TR-0103, White Sands Missile Range, New Mexico.

4. Nelson, J.G., W.M. Farmer, V.E. Bowman, and J.E. Steedman, 1982, "A Summary of Obscurant Characterization in Smoke Week IV, Volumes I and II," U.S. Army Project Manager for Smoke/Obscurants, Report No. AD B066107, Aberdeen Proving Ground, Maryland.

5. Burgess, E.W. and L.M. Nielsen, 1982, "Test Report, Smoke Week IV," Dugway Proving Ground Document No. DPG-FR-82-314.

6. Turner, D.B, 1961, "Relationship Between 24-hour Mean Air Quality Measurements and Meteorological Factors in Nashville, Tennessee." Journal of Air Pollution Control Association.

7. Hanna, S.R., 1984, "The Exponential PDF and Concentration Fluctuations in Smoke Plumes," paper presented at IFAORS Short Course No. 480 on Atmospheric Transport and Diffusion, Williamsburg, Virginia, July 10-13, 1984.

8. Farmer, W., 1984, Personal Communication. Science and Technology, Inc. Las Cruces, New Mexico.

9. Nielsen, L., 1984, Personal Communication. Dugway Proving Ground, Utah.

10. Cheney, C.S. and R.K. Dumbauld, 1979, "User's Instructional Manual for Smoke Model Computer Program (HECSMOKE-I)," H.E. Cramer Corporation. Technical Report TR-7930701. Prepared for U.S. Army Dugway Proving Ground.

11. Pennsyle, R.O. and R. Winkler, 1985, "Computer Program for Smoke/Obscurant Hazard Prediction (HAZRD2)", Chemical Research and Development Center report CRDC-TR-84071, U. S. Army Armament, Munitions and Chemical Command, Aberdeen Proving Ground, Maryland.

12. Whitacre, C.G. and M.M. Myirski, 1983, "Computer Program for Chemical Hazard Predictions (D2)", U.S. Army Armament Research and Development Command, Chemical Systems Laboratory, Aberdeen Proving Ground, Maryland.

13. Whitacre, C.G., P.E. Robinson, W.L. Kneas, and A.L. Freeman, 1977, "Computer Program for Chemical Hazard Prediction," Technical Report ARCSL-TR-77049, U.S. Army Research and Development Command, Chemical Systems Laboratory, Aberdeen Proving Ground, Maryland.

14. Matise, B. K., J. W. Petraska, T. J. Rogue, and F. G. Smith, 1983, "Smoke Obscuration Effects Model," Final Technical Report, OMI-83-012, OptiMetrics, Inc., Ann Arbor, Michigan.

15. Huang, K.H. and W. Frost, 1982, "Monte Carlo Model Development," FWG Associates, Inc., Tullahoma, Tennessee.

16. Huang, K.H. and W. Frost, 1984, "Monte Carlo Particle Dispersion (MoCaPD) Model of Battlefield Obscuration." FWG Associates, Inc. Tullahoma, Tennessee.

17. Ohmstede, W. and E.B. Stenmark, 1981, "Parameterization of the Dispersion of Battlefield Obscurants," Proceedings of the Smokes/Obscurants Symposium V, OPM Smokes/Obscurants Technical Report DCRPM-SMK-T-001-81.

18. Hoock, D.W., R.A. Sutherland, H.W. Maynard, and B.L. Thomas, 1982, "Combined Obscuration Model for Battlefield Induced Contaminants, Chapter 1." U.S. Army Atmospheric Sciences Laboratory, Report EOSAEL82, Vol. 3, Duncan et al. editors. White Sands Missile Range, New Mexico.

19. Hansen, P.S., 1979, "Mobile Smoke for APPLE II+ Microcomputer," Atmospheric Sciences Laboratory, Report ASL-TR-0155, New Mexico, 1979.

20. Ludwig, F.L. 1977, "A Theoretical Dispersal Model for Aerosols," Stanford Research Institute International, Report TR-T-CR-78-3, Menlo Park, California.

21. Petersen, W.B., J.A. Catalano, T. Chico, and T.S. Yuen, 1985, "INPUFF - A Single Source Gaussian Puff Dispersion Algorithm, User's Guide," U.S. Environmental Protection Agency, Report No. EPA-600/8-84-027, 1985.

22. Petersen, W.B., 1985, "An Evaluation of INPUFF with the MATS Data Base," IN: Proceedings of the DOE/AMS Air Pollution Model Evaluation Workshop, Kiawah, South Carolina, October 23-26 1984, Report DP-1701-1 of Savannah River Laboratory, Aiken, South Carolina, Eds. A. Weber and A. Garrett.

23. Mikkelsen, T., S. Larsen, and S. Thykier-Nielsen, 1984, "Description of the Risø Puff Diffusion Model," Nuclear Technology, Vol. 67.

24. Mikkelsen, T., 1982, "A Parametric Description of a Skewed Puff in the Diabatic Surface Layer," Risø National Laboratory Report Risø-R-476, Roskilde, Denmark.

25. Boughton, B. and W. Dunn, 1984, "Turbulent Atmospheric Transport of Particles with Settling and with Deposition," Department of Mechanical Engineering, University of Illinois at Urbana.

DISTRIBUTION LIST

No. of Copies	
15	Commander US Army Medical Bioengineering Reasearch and Development Laboratory ATTN: SGRD-UBG-M Fort Detrick, Frederick, MD 21701
12	Defense Technical Information Center ATTN: DTl-DDA Cameron Station Alexandria, VA 22314
5	U.S. Army Medical Research and Development Command ATTN: SGRD-RMS Fort Detrick, Frederick, MD 21701
1	U.S. Army Medical Research and Development Command ATTN: SGRD-PLC Ft. Detrick, Frederick, MD 21701
1	Project Manger for Smokes/Obscurants ATTN: AMCPM-SMK-T Aberdeen Proving Ground, MD 21005
1	Commander U.S. Army Environmental Hygiene Agency ATTN: HSHD-AD-L Aberdeen Proving Ground, MD 21010
1	Commander U.S. Army Environmental Hygiene Agency ATTN: HSHB-OA Aberdeen Proving Ground, MD 21010
1	Commander U.S. Army Armament, Munitions and Chemical Command ATTN: DRSMC-SG(R) Rock Island, IL 61299
2	CDR U.S Army Medical Bioengineering Research and Development Laboratory ATTN: SGRD-UBZ-I Fort Detrick, Frederick, MD 21701

1 Commander
10^{th} Medical Laboratory
ATTN: AEMML-PM
APO, NY 09180

1 Commander
7^{th} Medical Command
ATTN: AEMPS-P
APO, NY 09102

1 Commander
U.S. Army Medical Command-Korea
ATTN: EAMC-H-L
APO, San Francisco 96301

1 Commander
U.S. Army Material Development and Readiness Command
ATTN: AMCSG
5001 Eisenhower Avenue
Alexandria, VA 22333

1 HQDA (DASG-PSP)
Washington, DC 20310

1 Chemical Research and Development Center
ATTN: DRSMC-CLY-A
Aberdeen Proving Ground, MD 21010

1 Chemical Research and Development Center
ATTN: DRSMC-CLT
Aberdeen Proving Ground, MD 21010

1 Commander/Director
U.S. Army Atmospheric Science Laboratory
ATTN: DELAS-AR-M
White Sands Missile Range, NM 88002

1 Commander
U.S. Army Test and Evaluation Command
ATTN: DASTE-PP
Aberdeen Proving Ground, MD 21005

1 Commander
U.S. Army Dugway Proving Ground
ATTN: STEDP-MT
Dugway Proving Ground, UT 84022

1 Commander
US Army Research Office
ATTN: AMXRO-GS
P.O. Box 12211
Research Triangle Park, NC 27709

1 Dr. Joseph Shinn
Environmental Sciences Division
Lawrence Livermore Laboratory
P.O. Box 5507
Livermore, CA 94550

END

FILMED

1-86

DTIC